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Tesi di Laurea

"Precast concrete panels for the Chinese market: the application of the Performance-Based Building Design approach to define a database of technological solutions"

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This Thesis is dedicated to my friend
Alessandra Pelizzi

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PREFACE

Abstract

Nowadays the sector of prefabricated constructions is subjected to continuous progress and it is moving towards high quality design solutions, all developed following more sustainable approaches. At the base of this method there is the conviction that the construction must be born entirely in the factory. Once out of the plant, prefab components are already completed with finishes, windows and they require only operations of assembly and sealing. It represents one of the most employed buildings' technologies and every year it creates an enormous amount of incomes and employments worldwide. By now, thousands of housing, public and industrial buildings have been built with this method, especially in Asia, North America, Oceania and United Kingdom.

Within the wide range of prefabricated components, prefab claddings and in particular precast concrete panels are playing a stunning role as innovative solution of building's envelope. There are many researches which have been carried out over the years to transform the prefabricated envelope into an ingenious and satisfactory interface. Compared to on-site claddings, emerge some indisputable advantages such as flexibility, long-term life cycle, strict controls of manufacturing quality, vast possibility of aesthetic customisation, low production and assembly costs. Precast concrete claddings are especially appreciated in high-rising constructions thanks to the speed of all constructing operations and contained employment of workforce. Considering an international prospective, China has demonstrated outstanding expertise in the use of this cladding technology triggered by the swift in urban development which has taken place since 1980s. However, despite the remarkable expansion, China is facing with the harsh environmental pollution and resources exploitation added to inherent issues such as seismic activities and demographic increase. In order to tackle these problems, the reply from the construction sector is to strive for elaborating

more advanced technologies which in cladding field deal with the enhance of traditional precast concrete claddings' performances. In this regard, this Thesis aims to take stock of the contemporary applications of precast concrete cladding and, following performance-based building design (PBD) approach, propose a database for precast panels technical solutions. The PBD method has been selected as an indispensable guide for the elaboration of Thesis' different steps. Thanks to the principles of this method, it has been possible to follow precise stages, from the collection of the stakeholders' needs to the definition of the related performance requirements, which have brought to the design of PAN-dwich, the database for precast panels technical solutions. It stands as a practical tool proposed to lead the professionals towards the most suitable technical solutions which can fit their projects, optimising also their workflow and inspiration.

Aims and motivations

The Thesis' main goal is to design the database for precast panels technical solutions called PANdwich. It has been thought to be an intuitive and user-friendly tool able to support the professionals in the selection of the most suitable technical solution in the broad and complex world of precast panels. This final project has been the result of the analytical process carried out by the cooperation between two research groups: the first one is composed by the Tongji University's structural engineering students, headed by professor Sun Feifei, and the second one is composed by the Politecnico di Torino's architecture student, headed by professors Lorenzo Savio and Silvia Tedesco. It is also important to mention the Sino-Italian Workshop "SHANGHAI 2035 – striving for the excellent global city", carried out under the aegis of Tongji University, Politecnico di Torino, Italian Ministry of Environment, Italian General Consulate in Shanghai and China Center, whose meetings and contents have stimulate the development of this work.

As a student of Master's Degree in Architecture for the Sustainability Design, I seized the opportunity of this Thesis to get in touch with a new culture from all points of views. During the time I spent in Shanghai cooperating with professor Sun and his students, I realized the complexity of Chines building requirements and frameworks, quite different from Italians ones. Indeed, China is living a central historical changing in terms of energy supply in every field: its staggering economical growth is about to pass from the dependence of fossil fuels to a larger exploitation of renewable resources. This is ascertained by enormous investments in more sustainable approaches that involve also the construction sector. Hence, it is the most harmful field together with industry and transports. Given that precast concrete structures are the most applied construction technologies to build Chinese cities, I capture the opportunity to work on how to turn this solidify practises into a more efficient systems considering both architectural and engineering aspects.

Methodological framework

PART I – STATE-OF-THE-ART

STEP I — PREFABRICATED CLADDING SYSTEMS
The introduction of **the general topic**, analysed from architectural and engineering point of view

STEP II — PRECAST CONCRETE PANELS
The study of **the key topic**, analysed from architectural and engineering prospective

STEP III — PERFORMANCE-BASED BUILDING DESIGN APPROACH (PBD)
The outline of **the key methodology** embracing all the project's steps

PART II – THE CONTEXT

STEP IV — CHINESE REAL ESTATE MARKET
The the main aspects of the **principal context in which the thesis is developed**

STEP V — CHINESE STAKEHOLDERS NEEDS
The breakdown and analysis of stakeholders' needs to run the project

STEP VI — PRECAST PANELS PERFORMANCE REQUIREMENTS
The breakdown and analysis of performances requirements to run the project

PART III – THE TOOL PROPOSAL

STEP VII — PANdwich
THE DATABASE FOR PRECAST PANELS TECHNICAL SOLUTIONS
The framework and the employment simulation of the practical tool developed as the final goal of the thesis

Part I – State-of-the-art

1. CURRENT KNOWLEDGE IN BUILDING PREFABRICATION

1.1 Prefabricated cladding systems

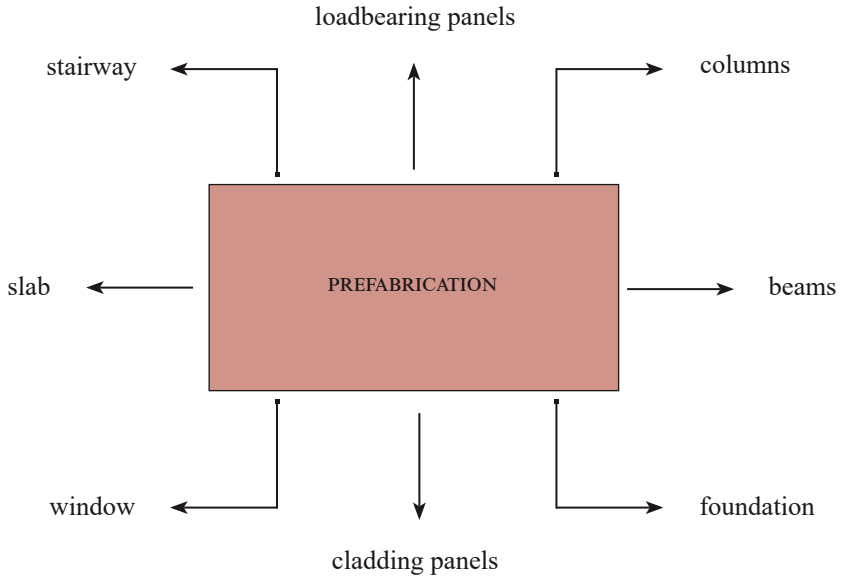
Prefabrication is defined as «the practise of assembling components of a structure in a factory or in another manufacturing site and transporting complete assemblies or sub-assemblies to the construction site where the structure is located» (Campioli & Lavagna, 2013).

As stated in the definition, the key concept of prefabrication consists in the place where construction elements are produced and the way in which they are realised. The merit of having introduced changes in the production and construction processes of buildings is attributed to industrialization. Nowadays, this has allowed to move many processes, which were previously carried out on the construction site, inside the industrial plants. Once built, the components are transported to the site as ready-made parts to be assembled. However, it still exists the opportunity to employ one of two mentioned methods of construction: on-site or using prefabricated components. An example can be load-bearing structures made by reinforced concrete. There are also cases where the entire building is prefabricated, that is, where all the parts that make up it were made in the factory and simply assembled on site. While the on-site construction allows dimensional adjustments and it does not force the designers to be very attentive to dimensional control, the use of prefabricated components require that the designers crucially consider the accuracy of whole elements' dimensions and the relationships among the parts. This means that, in the case of prefab systems, the tolerance between the designed elements and the constructed ones is in the order of the millimeter, significantly lower than on-site technique. Often the size of the prefabricated components depends on the production supply; at the same time, the current flexibility of the production processes also allows special productions. Indeed, it is possible to realise components which suit the required specifications of the specific project, without adding excessive costs.

Comparing prefabricated elements with those built up on-site, substantial differences emerge: for example, in the case of masonry walls, the modularity of the bricks pattern is often poorly controlled due to the fact that, in the construction site, the length and height of the wall is

continuously adjusted to meet the design desired. The same goes for insulating material panels which are cut according to the surface of the envelope needed to be covered. These practices create also extensive waste which can be disposed only in the landfill.

Nowadays, on-site and prefabricated methods coexist and are associated with the different components of the building: typically, the load-bearing structures are made on the construction site while the envelope, windows, columns, beams, foundations, cladding panels, slab, stairway are prefabricated elements simply assembled. Finally, the choice between the two depends on the complexity of the project: generally, the prefabrication is favored for big scale buildings.



The brief history of prefabricated buildings

The first more renowned example of a partially prefabricated building is Paxton's Crystal Palace, erected in London in 1851 to house the Universal Exposition. The cutting-edge building was born by a steal structure characterised by compact sections elements, all fabricated with industrialised methods. However, the success of this new technology happened within the end of the IXX century and the First World War. The gory conflict carried out the necessity of constructing numerous temporary and emergency buildings in a short time, minimising the costs. Between the two World Wars, the construction sector made important experiments on the prefab systems achieving new solutions such as Dorlonco, widely employed in UK. Over-

came the Second World War, prefabrication was more broadly used in civil applications such as housing and educational buildings. The purpose was always to reduce the costs and time, basic needs requested in the reconstruction period after the 1945. Moreover, in this period were taken the first steps toward the standardisation of prefab systems in order to make the realisations safer and homologated. Some illustrious architects, such as Le Corbusier, were fascinated by this technology and wanted to experiment it in their design. The 1970s was a decade where two issues emerged: the first one was the consequence of the oil crisis which obliged to find new materials and industrialized techniques to make building more efficient from an energetic prospective. The second issue was the acknowledgment that the post-war prefabricated buildings were built often at the expense of quality, causing untimely deterioration and loss of minimal watertight and fire resistance requirements. This brought about huge critics on this building typology which affected its popularity worldwide. The successive two decades, 1980s and 1990s, saw a substantial recovery of industrialized architecture thanks to the renovated orientation towards innovative materials, customised design solutions and new production processes. Everything was put in place to assure a better comprehensive quality of prefab components; this always flanked the main advantages of serial constructions which are low costs and reduced time. In the early 2000s, the incessant research led to the ask of new requirements related to the reduction of environmental impacts and the sustainable development in buildings. The initials higher costs due to the employment of new efficient features was quickly compensated by the big benefits in terms of versatility and efficient.

Cladding functions

By cladding systems is meant the elements which are external to the structure and create the shell of the building, also called envelope (Campioli & Lavagna, 2013). Hence, the main purpose is to enclose the structure and to divide it from the external environment. Moreover, they play a crucial role in defining the outside appearance and the inside spaces. Indeed, at the first glance, the façade is the primary image of a building and so it is responsible for the first impression of the viewers. For this reason, the envelope should display not only architectural expression and interesting shapes, but also it should contribute to du-

rability, sustainability, energy efficiency, and improve occupant comfort and safety. Thus, its relevance is fundamental also in terms of interior ambiences and occupants' comfort. Following the same logic and definitions proposed by Andrew C. Baird in "Seismic performance of precast concrete, cladding systems" (Baird, 2014), the functions of the cladding panels could be divided into two categories: primary and secondary. The primary functions consist in the fundamental architectural requirements that the panels should fulfil:

- «Define the aesthetic image of the building;
- Keep water out of the building;
- Prevent air leakage;
- Control the passage of light and heat (radiation and conduction);
- Control sound from the outside;
- Avoid thermal bridges.»

The secondary functions are referred to derived aspects which count:

- «Adjust to movement in the building due to wind, earthquakes, creep, etc.
- Adjust to thermal expansions and contractions;
- Control the passage of water vapour;
- Resist fire;
- Resist weather conditions gracefully (without streaking, oxidation, corrosion, freeze-thaw spalling).»

As stated by Andrew C. Baird in the same Thesis, the present innovations on cladding panels are oriented towards an enhancement of primary functions, especially the contents which involve energy efficiency and occupant's comfort. These indoor and outdoor concepts are strictly related to the performances displayed by the building's envelope and, in particular, by its materials employed, the thicknesses designed, and the insulation devices supplied. These qualities are more and more often assessed by multicriteria rating systems which certificate the degree of sustainability taking into account numerous building's parameters. The

purpose is to sensitise designers and constructors to improve the environmental quality of buildings and components in order to develop the so called “green building” or “low energy buildings”. The assessment protocols can be provided at national level, such as the “Protocollo Itaca Nazionale 2011” for Italy, or at international level, such as LEED (Leadership in Energy and Environmental Design) delivered by USGBC (U.S. Green Building Council) and BREEM (Building Research Establishment Environmental Assessment Method) delivered by BRE.

Fig. 1.1 USGBC, BREEM & ITACA logos (Url 1,2,3)

Cladding classification

Due to the huge variety of cladding systems currently available on the market, it important to classify the most relevant typologies to make the further considerations clearer. Different types are applied for different uses buildings: from residential as well as retail, to industrial as well as services. Moreover, the envelope systems are designed to consider the performances required in a specific area, such as earthquakes’ protection or extra insulation due to the harsh weather. Sometimes it happens that in the same building are employed different typologies of cladding in order to meet different needs. Despite this large array, it follows a brief list proposed by Andrew C. Baird (Baird, 2014), with further considerations of Precast Concrete Institute (PCI, 2007).

- Curtain wall
  - Stick curtain
  - Unitised system
  - Structural glazing
  - Frameless glazing
- Double skin
- Monolithic cladding
- Masonry veneer

- Lightweight panels
- Heavy panels

- *Curtain wall*

The curtain wall cladding has been adopted since 1960s and it is applicable for buildings characterised by columns and beams structure. It is defined as “curtain wall” because the envelope covers continuously the loadbearing frame, without interruptions in correspondence of slabs and pillars (Campioli & Lavagna, 2013). They are designed to span multiple floors. Generally, the width of the window part is ampler than the wall one. Curtain wall panels are not loadbearing elements, they are composed by repeated prefabricated units, they are reversible and they are assembled thanks to bolts and sealants. Curtain wall panels are the most generic definition of lightweight cladding systems which include four sub-typologies: stick built system, unitised system, structural glazing, frameless glazing.

Stick curtain

The stick curtain system is composed by aluminium frame consisting of continuous perpendicular transoms and mullions characterised by a hollow section. This structure encompasses pieces of glass or thin opaque panels. It is bolted to the building frame in correspondence of slabs. Mullions have generally a length of 50 mm and a profundity which depends on the span between two slabs (Campioli & Lavagna, 2013). The final image of the façade seems to be made predominantly by glass.

Fig. 1.2 Curtain wall cladding system: stick curtain (Url 4)

Unitised system

The unitised systems are constituted by prefab modular elements with a height which covers the span between two slabs. The frame of transoms and mullions, the glass and the opaque parts are put together in the plant as a single panel and then, once reached the construction site, it is just lifted in the required position.

Fig. 1.3 Curtain wall cladding system: unitised system
Jin Mao Tower (Shanghai,2019)

Structural glazing

The first step to obtain the structural glazing is to seal the perimeter of the glass pane to a primary aluminium or steal frame. Secondly, it is connected to the transom and mullion frame. The perception from outside is to have a uniform façade, which emphasises the clear part and hides the structural frame. The continuity is interrupted only by the grout line between two glass panes.

Fig. 1.4 Curtain wall cladding system: structural glazing
Shanghai Tower (Shanghai,2019)

Frameless glazing

Frameless glazing, also called spider glazing, is constituted by particular laminated glass panes equipped with connectors in the corners of the glass. These connectors are the joints which bolt the glass panes to the stainless steel structure. The applications as external cladding are not very common due to the complex design and the consequent high costs.

Fig. 1.5 Curtain wall cladding system: frameless glazing
Shanghai Grand Theatre (Shanghai,2019)

- *Double skin*

The double skin cladding system is characterised by two paralleled layers of envelope which create an air cavity between them. This design allows to enhance the thermal performance of the building. The units of the façade are generally prefabricated and lifted on the construction site.

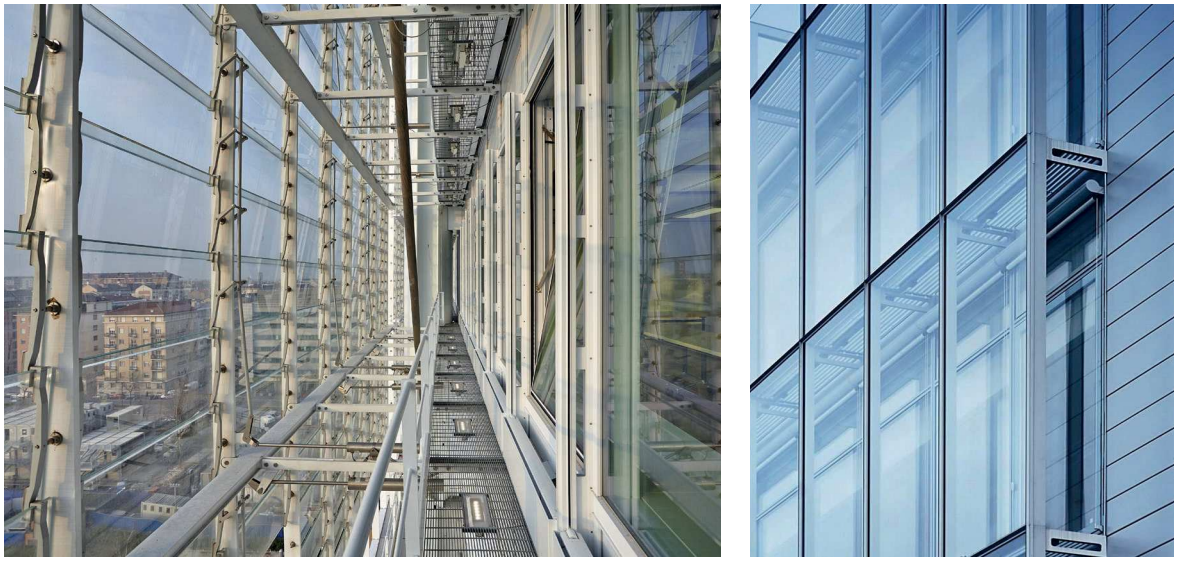


Fig. 1.6 Double skin cladding system (Url 5,6)

- *Monolithic cladding*

Monolithic cladding systems are functional to obtain a seamless façade: the grout lines are covered by two or three layers of sand-cement plaster which create an image of uniformity and continuity. Generally, the external finishes are made using an acrylic coating in in order to guarantee watertight surface. These systems are often employed in residential constructions and they are brittle.

Fig. 1.7 Monolithic cladding cladding system (Url 7)

- *Masonry veneer*

The typical masonry veneer cross section is constituted by a single layer of brick. It is allow to have an additional air cavity in order to prevent the water infiltration through the veneer. The air cavity can also provide thermal insulation. These systems are usually employed for low-rise construction with a residential use.

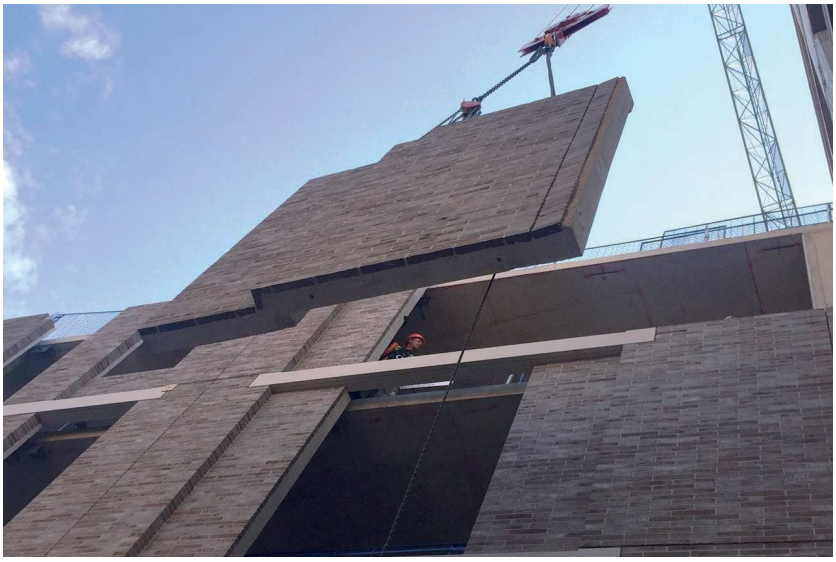


Fig. 1.8 Masonry veneer cladding system (Url 8)

- *Lightweight panels*

Lightweight systems are a wide definition which encompass an ample array of cladding panels made of various materials. They include wood, metal and concrete. They are economic envelope solutions and for this reason are commonly employed in different uses buildings. Precast concrete panels are included in lightweight panels whether they are characterised by low density, otherwise they belong to heavy panels typology.

Fig. 1.9 Lightweight panels cladding system (Url 9,10)

- *Heavy panels*

Heavy panel cladding systems includes concrete and stone cladding panels. Precast concrete panels are the most widespread type used in commercial, residential and industrial buildings. Precast concrete panels are examined in depth in the following paragraphs.

Fig. 1.10 Heavy panels cladding system (Shanghai,2019)

Cladding modularity

A module is usually described as a component of a larger system, which collaborates with the other components in order to define the entire system (Steinø, 2017). Although each module has inherent properties, the properties of the whole system are defined by the sum of single unit. Thus, the units' attributes and the accuracy with which the numerous parts are jointed determine the ultimate performances of the system. Therefore, modularity is the way according to which units can be arranged and divided. Modularity represents for cladding systems the scheme of single panels which constitutes the entire façade. The modularity tells the arrangement of the cladding components and, depending on the layout which the units display, it can be classified differently. The classification of the modularity implies directly how the cladding system show its mechanical, acoustic, energetic, durability performances. The logic applied to describe the different examples of cladding modularity is based on the number of cladding panels which cover a single storey and single bay of a structural frame (Baird, Palermo, Pampanin, Riccio, & Tasligedik, 2011).

- *Mono panel*

The elementary modularity is identified by the arrangement of the mono panel system. It is formed by a single panel that occupies a single bay. Its characteristics make it indivisible in smaller subsystems.

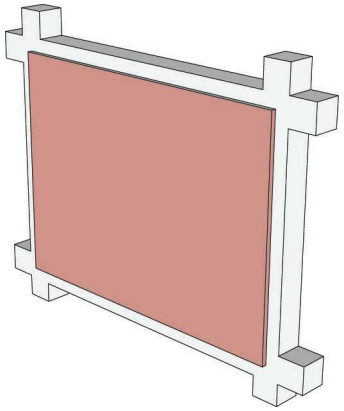


Fig. 1.11 Mono panel cladding modularity

- *Dual panels system*

If the mono panel is separated in two equal parts, it becomes a dual panel system. The cladding modularity is expressed by two panels with the same width that occupy a single storey and single bay. In this context, the two elements can be organised either horizontally or vertically by twos. However, the most common configuration for cladding systems includes the parallel disposition of two horizontal panels.

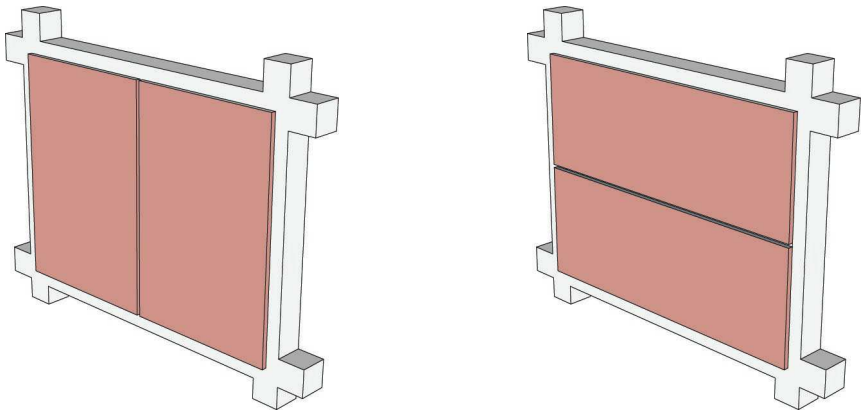


Fig. 1.12 Dual panels cladding modularity

- *Matrix panels*

It is possible to increase the complexity of the modularity dividing the mono panel into more numerous elements, filling the bay of a structural frame with rows and columns. Thanks to this schematisation, the cladding system is described according to a matrix, for instance 4x3 as the following example.

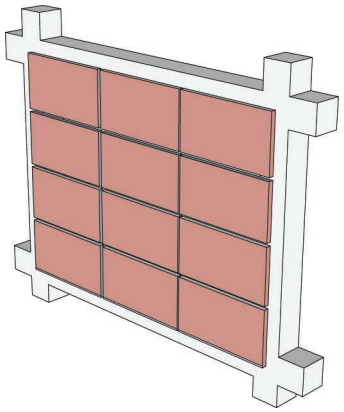


Fig. 1.13 Matrix panels cladding modularity

- *Spandrel*

Another arrangement is constituted by the so-called spandrel. They count precast concrete panels attached only along the beam and/or column lines.

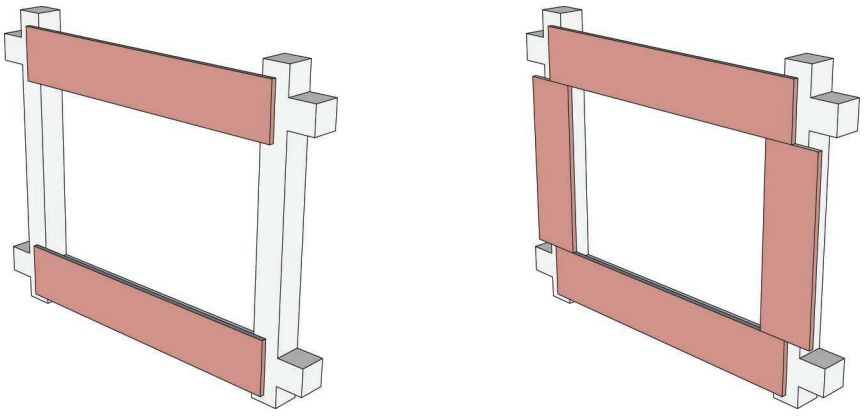


Fig. 1.14 Spandrel or cover panels cladding modularity

- *Single or multiple punched panels*

The last configuration is called punched holes in panels. The most common practice is to punch the panel in the centre obtaining a single opening . Moreover, the single panel can be multiplied several times to obtain multiple openings.

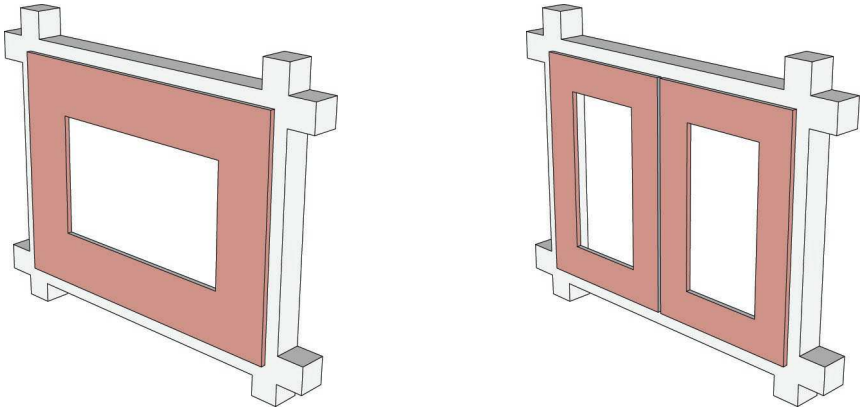


Fig. 1.15 Single or multiple punched panels cladding modularity

Cladding connections

In precast cladding panels connectors are the essential components of the system. Indeed, they are requested to link the structural frame (breams, pillars etc.) to the cladding panel. Hence, they deserve a specific detailed study because the mechanical behaviour of the cladding panels are strictly related to their performance. Design team must pay attention to the choice of the connector bodies due to the fact it has been seen, thanks to laboratory tests, that they often represent the weakest and least stiff parts of the cladding system. As it is assumed in *Passive control of building response using energy dissipating cladding connections* (Pinelli, Craig, Goodno, & Hsu, 1993), there are always five elements which constitute all cladding systems: «the structural framing member, the attachment between structure and connection, the connector body, the attachment between connector body and the cladding panel». If the attachments between structure and connection as well as between connector body and the cladding panel are characterised by strong stiffness, the connector body encompasses the structural link between the cladding panel and the main structure, accommodating the relative

movements between the two parts. It is typically realised by steel angles and bolts or other steel components. They can be welded or bolted depending on several design considerations. The classification is carried out according to the different connector bodies: as proposed by Andrew C. Baird, here below it follows the five main typologies. In order to simplify the dissertation, it must be noticed that all the technical details about these elements will be avoided, reporting only the prementioned lists with some correlated imagines (Baird, 2014).

- *Bearing connection*

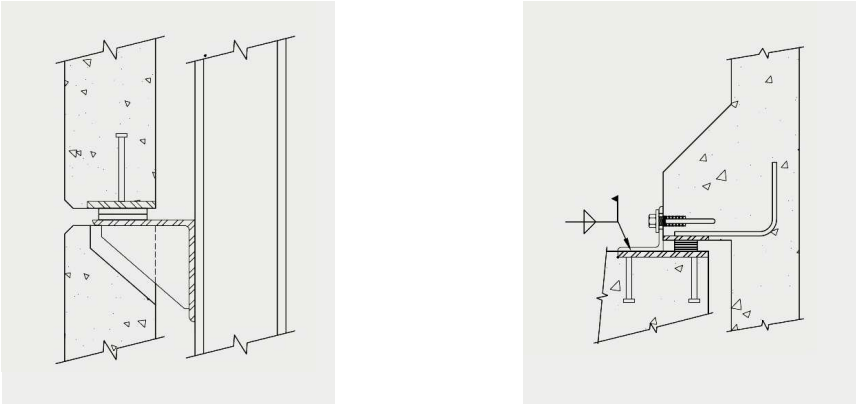


Fig. 1.16 Examples of bearing connection (PCI, 2007, p. 334)

- *Tie-back connection*

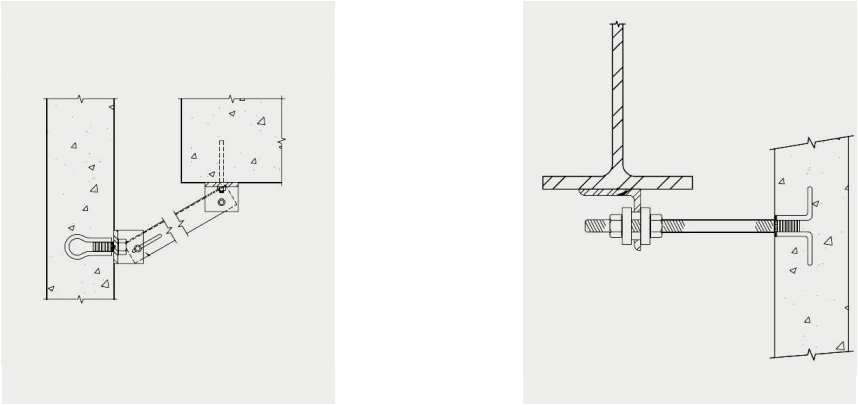


Fig. 1.17 Examples of tie-back connection (PCI, 2007, p. 336)

- *Slotted connection*

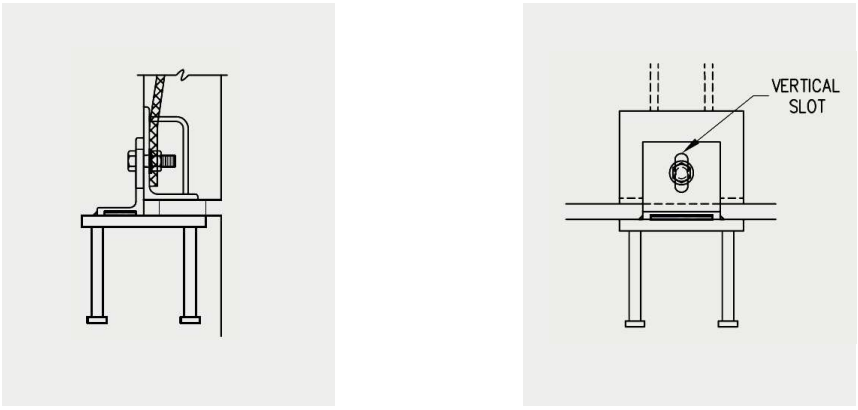


Fig. 1.18 Examples of slotted connection (PCI, 2007, p. 320)

- *Fixed connection*

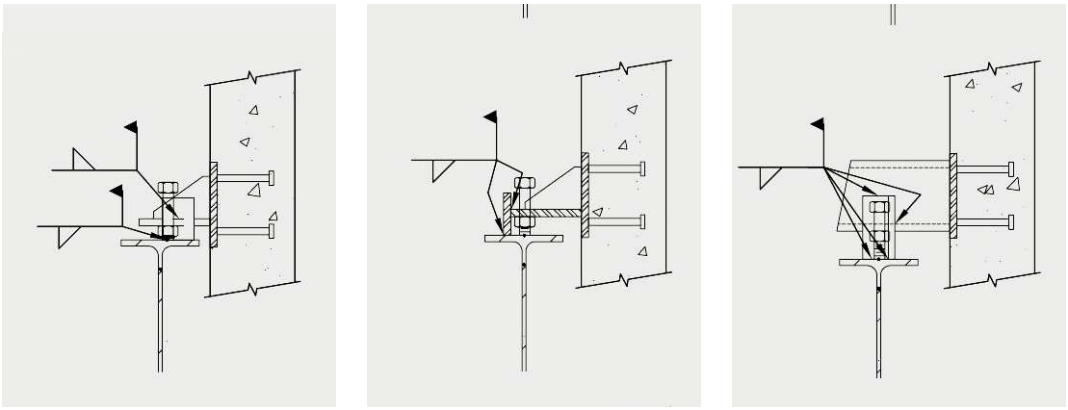


Fig. 1.19 Examples of fixed connection (PCI,2007, p. 339)

Connection modularity

Whether the cladding modularity is more associated to variety and aesthetic considerations, connection modularity responds to safety and loadbearing needs. Connectors are located on the columns, beams, floor and they can also be arranged encompassing two typologies together. This is functional to prevent potential creeps and additional damages such as the misalignment of the panel. Depending on the panel typology and shape the connectors modularity can change considerably. Here it follows a brief list of the most popular types of panels associated with their connectors usually used: rectangular mono panels are attached to the frame structure through bearing connections located at the bottom of the panel and the tieback connections to be located in the top corners. The bearing connections could be placed at the bottom or centre

of the panel in the case of column cover panels. Spandrel panels, instead, are connected at the floor level and also to vertical elements.

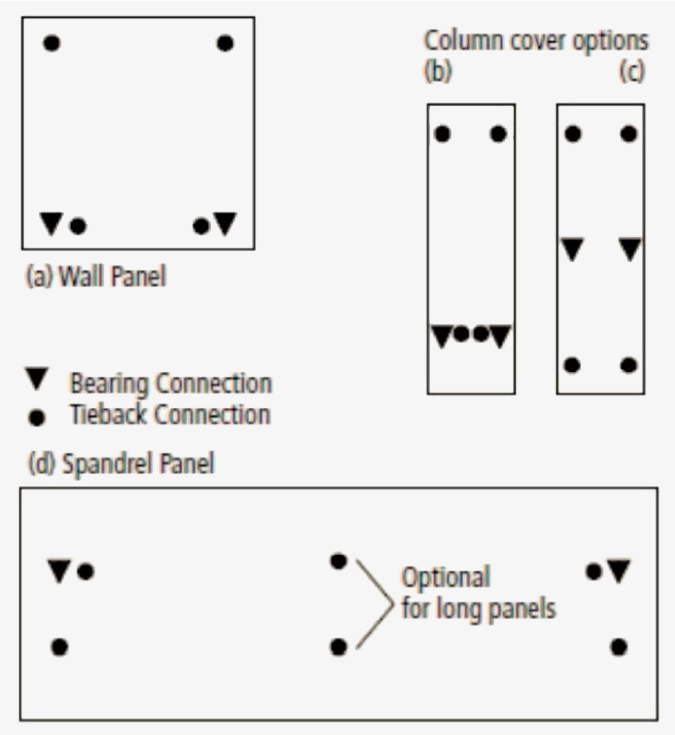


Fig. 1.20 More common arrangements of connections modularity (PCI,2007, p. 315)

1.2 Precast concrete panels

Precast concrete panels are one of the most employed cladding technologies across the wold, recording the peaks especially in Asia and North America. In the first instance, their popularity depends on the principal material employed for their production: the precast concrete. In the last decades, the quality of this material is continually rising due to improvements in proportioning, mixing, placing, finishing, and curing techniques. This advancement has allowed designers and users to benefit of more sustainable developed features, reducing costs and time. Conjunctly to these, appearance, durability, and other important aspects, such as transportation and erection, are steady developing their relevance and quality. Taking advantage of its property of plasticity and workability, concrete allows to design panels with a wide range of shapes and sizes to create architectural variety and enhance the overall aesthetic. Thanks to the selection and manipulation of the aggregate, precast concrete panels offer an extended array of patterns, colours, finishes and textures. Moreover, precast concrete has excellent characteristics in terms of thermal-acoustical insulation and fire and blast resistance. In terms of dimensions, concrete panels cover the height of one story, although they are forced to respect standardised width due to transportation and installation limits. Given that these panels are completely reversible, in the case of grave damages they can be replaced easily and, after the substitution, they guarantee all the performance requirements stated for the cladding. Consequently, thanks to the excellent durability of precast concrete, maintenance is limited and concentrated upon single item's degradation. For precast concrete, the mechanical resistance is another strong point: the panels are designed to resist wind, seismic forces and deformations caused by temperature. Depending on their capacity of bear loads, the precast concrete panels belong to two typologies: the first is non-loadbearing panels and loadbearing wall panels or spandrels. All the further steps of the thesis will take into account only non-loading panels as cladding system.

Main production phases of a traditional precast concrete panel

1. The first step of production encompasses the formation of the first concrete layer of the future panel. Initially, an electro-welded mesh and spacers are organized in a mould to cover the requested dimension of the panel. Once casted, the wet concrete is vibrated to obtain a homogeneous thickness. Generally, in big plants, the concrete cast is handled by using a a bridge crane on which is hung up a bucket in charge of spreading the concrete in the formwork (Pappalardo, 2018).

Fig. 1.21 Precast concrete panels plant (Url 11)

2. The second step deals with the installation of the insulation. This phase is managed paying attetion to the joints between the insulating panels in order to prevent heat dispersion and moisture formation.

3. The third step is focused on the production of the structural layer. Following the same practise of the first step, after the cast, the concrete is vibrated and levelled.

Fig. 1.22 Precast concrete is vibrated and livelled (Url 12)

4. The last step deals with the curing of the concrete: this phase is essencial to obtain a high quality final panel. To optimise and speed up the process, the panel is immerse in steam or hot air. After the curing, the panel is stored, ready to be transported to the construction site. It is always important to avoid geometrical variations triggered by unexpected stresses produced by general inaccuracy and movements during the ride.

Fig. 1.23 Precast concrete panels are loaded on the trailer to be delivered (Url 13)

Main characteristics

- *Generals*

  First of all, the speeding up of construction time with a significant reduction in costs have always been the key advantage of prefabrication. This is linked with the possibility of relying on certain time scheduling, the higher executive quality of final product compared to those carried out in on-site procedures. This is allowed thanks to the industrial controls which reduces the need of skilled workers on the construction site, replacing them with the ease of assembly operations. Another general pro concerns about the relations which are set up among the different performers who are involved in the design of precast concrete: it is essential to establish a close collaboration between architects and the local precast concrete producers starting from the earlier stages of the design. This teamwork is crucial to obtain high quality products at a minimum assembly cost.

- *Flexibility*

  One of the most forceful features of precast concrete panels is their possibility to be arranged in various ways, both from connections and visual sides. They are totally reversible. They can be attached to the framing with different typologies of joints, especially designed to suit structural and environmental needs. In addition, they can be configured in numerous shapes, dimensions and layouts. Throughout their operational life, they can be removed from the framing to allow the enlargement of the building and then, once completed, they can be reinstalled and flanked with new ones. In case of damages or loss of initial performances, they can be easily replaced without undermining the entire construction, reducing costs and rationalising the time.

- *Durability*

  Precast panels durability resides in the concrete mix design and how it is casted. The correct choice of aggregates dimension and the content of water are the two main aspects which carried out an appropriated mix design. In particular, durable concrete components are realised through a low water-cement ratio adding chemicals which make the concrete superfluid.

This means that, after the cast and when the concrete is still fresh, the mixture can settle and start to become compact (with a low porosity ratio) without the use of vibrators or generally extra manufacturing. All these processes are conducted in the factory, environment where temperature and humidity are constantly controlled in order to ensure the most suitable curing. If all the steps are done in the proper manner, the result will be a highly durable concrete panels which provide buildings with façades resistant to abrasion, corrosion, weathering, explosions, making it virtually maintenance-free and preserving the building's original look (PCI, 2007). Prefabrication is the key word for precast concrete panels: indeed, differently from the concrete casted on-site, the concrete panels are undergone to a strict steps of manufacturing control carried out by the precasters. This is the assurance of obtaining an high quality final products because all the plant's steps are organised to guarantee the best manufacturing ambience such as high degree of relative humidity and controlled temperature.

- *Surface Aesthetics*

The main aesthetical advantage of precast concrete panel is the enormous variety of customisation which is available for the design. They have a large creative freedom in terms of architectural language, sizes and shapes. This is allowed thanks to the characteristics of concrete: first of all, in the primary manufacturing steps, its plasticity and its ability to be processed with few work make it perfectly employable to achieve complex visual elements such as textures, bullnoses and ribs. The use of precast concrete mould-building method gives the opportunity to create boundless solutions acting on colour, texture, and other details. For every building is possible to define a various range of aggregates, color tones, textures, and patterns which lend an appearance of strength and novelty. Concrete exhibits an impressive aesthetical durability of exterior surface because it does not require painting, being virtually eternal. Moreover, precast concrete is predominantly indicated in the necessity of integrability and compatibility with the existing buildings' aesthetics: indeed, the possibility of manipulating its components allows to recreate a vast range of finishes such as brick, tile, natural stone or terra cotta (PCI, 2007). The fact that precast concrete can resemble more expensive materials is another good aspect which is functional to decreases costs and gua-

rantee the harmonisation among the parts. Finally, its plasticity and the infinite shapes that moulds can have allow to model arches, cornices and decorative relief panels at low costs.

- *Initial Cost*

  Once again, the properties of precast concrete and its manufacture are essential to cut costs, in this case the initial cost. The reason is that after the casting and the curing processes the precast panels are already ready to be sent to the construction site and installed to the supporting structure. Thus, the overall speed of manufacturing and erection is relevant and the entire building schedule is limited within the year-round. This means that the building envelope can be enclosed quickly employing whether loadbearing or cladding panels. This triggers many economic advantages such as short-term financing, low construction costs, low management costs throughout the functional life and high potentiality to capitalize the completed building's value. Another annotation concerns about the savings gained from using loadbearing panels because they do not need the column along the perimeter. This procures extra saving from the littler width of framing and it can be also valid for interior columns which are replaced by additional loadbearing panels, incrementing the overall saving.

- *Life Cycle Cost*

  The life cycle cost is another positive aspect of precast concrete: the choice to resort to industrialised production processes, which use the most efficient technologies and expertise, allows to obtain more savings since serial and large-scale manufacture cost less than on-site one. Designers can outline a precast concrete façade with minimal maintenance due to it does not entail painting. Hence, the relevant initial cost to provide more high-performance components are payed off in long-term durability and preservation of the efficiency, defined during design phase.

- *Energy Efficiency*

  Energy efficiency is strictly related to the performance requirements which the envelope can fulfil. Moreover, the more demanding standards introduced for new constructions force the

designers to get down to work on high energy efficient buildings. To reach that, designers have a vast range of solution they can employ: first it is important to equip precast panels with a suitable thickness of insulation which can be arranged in their backs or be incorporated in the case of sandwich panels. In the same vein, the high thermal mass inertia of concrete is a powerful characteristic which allows to make the indoor temperature stable diminishing the temperature swings. Therefore, there are additional devices which can reduce irradiation peaks and solar gain such as brise-soleil and other shading elements. Also, the characteristics of window frame and glass panes are important to lessen the transmittance value and the thermal control during cold seasons. In order to maximise the efficiency of the envelope, designers can typify each face of the façade with specific thermal properties according to the exposure. In addition, the control of air infiltration and exfiltration provides the decrease of the potential moisture problems. Thus, the more the precast concrete panels are energy efficient the more it will be possible to reduce heating and cooling costs. This means that thanks to the control of heating peaks and cooling loads is guarantee their translation into cost saving.

- *Environmental Impact*

  It is certified by many assessment models that concrete is an high embodied energy material with a substantial environmental impact. Considering the entire lifecycle, it is essentially due to its manufacturing which is characterised by high consumption of non-renewable resources causing consequently a big emission of harmful pollutants (carbon dioxide, sulfur dioxide, nitrogen oxide…). Added to this, once the precast panels are ready to be delivered, there is the transportation and installation phases which contribute to increase the total impact. Moreover, arrived at the end-of-life, concrete is difficult to be recycled unless it goes through some processes of milling which make the material employable as an aggregate to produce new concrete. However, these techniques are costly and the final outcome has low performances. Thus, the simplest act taken to dispose precast concrete is to landfill it. However, precast concrete panels have remarkable benefits to diminish environmental impacts: if they have an appropriate thermal mass, insulation thickness and shading devices they allow the shell of the building to be energy efficient, preserving the heat during the cold periods

and making as limited as possible the heating loads. On the other side, the same goes for cooling loads during summertime. Thus, energy efficiency is linked to low energy consumption (especially non-renewable resources such as oil, coal and gas) which are in turn matched to cost saving. In a certain way, light precast concrete can reflect solar irradiation as well as heat, decreasing the "heat island" effect which is the cause of bad thermal comfort in urban areas. Coming up to the components of precast concrete panels, they use scraps of other industries which previously were landfill items: an example are the mixture cements which reuse by-products from heavy industry or steel reinforcing bars which are made from recycled automobile chassis and metallurgic industry. Moreover, in case of modification of the building's layout, precast panels can be disassembled and successively reattached to the framing, reusing the same non-loadbearing wall panels. Another attribute of precast concrete is that it does not generate no toxic substances during its functional life. It is important to preserve the indoor and outdoor air quality. Finally, the precast concrete's mass is useful also to create a suitable acoustic environment, providing an economical acoustical barrier to exterior and interior noise penetration.

Precast concrete panels used as cladding

The most popular application of architectural precast concrete panels regards non-loadbearing precast concrete panels used as cladding. Non-loadbearing panels are defined as capable of resisting their self-weight, wind and seismic forces and of transferring the weight of the panel to the framing structure. As already seen for the numerous typologies of cladding systems, precast concrete cladding panels can be designed in an ample array of sizes and shapes, typically considering the vertical or horizontal dimensions the longest ones. In terms of bay and storey coverage, cladding wall units are usually equal or smaller than the bay and the storey width of the framing structure. Thus, their width is design according to the structural and architectural requirements: for instance, precast concrete panels are limited to floor-to-floor dimension. Among the main aspects already accounted in the section above, the flexibility of this systems is a bid strong point: in fact, single units can be removed and reinstalled without influencing the stability of the entire façade. The main typology of precast concrete panels as cladding units are:

- Solid wall panels
  - Solid wall panel
  - Ribed panel
  - Lightened panel
  - Sandwich panel
- Window wall units
- Spandrels
- Mullions and column covers

- *Solid wall panels*

Solid wall panels are the most traditional type of precast concrete unit and they are entirely composed by opaque part. This makes them remarkably stiff and strengths resistant. Solid wall panels benefit of the principal advantages of precast concrete units such as the large possibilities of customisation in shape, size, finishes and flexibility.

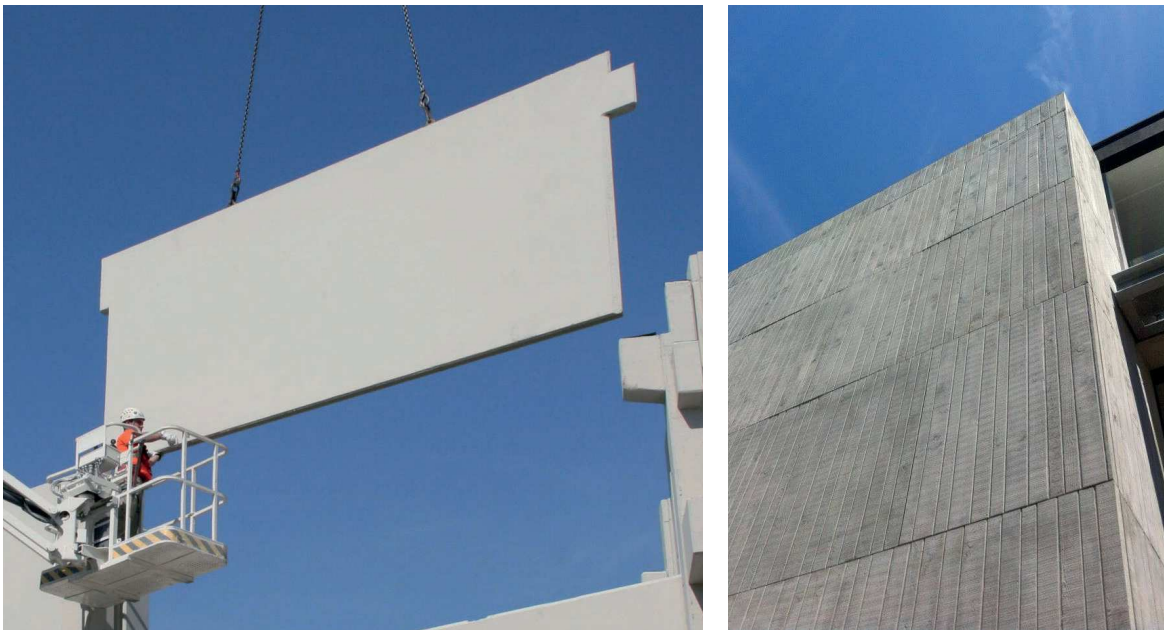


Fig. 1.24 Examples of solid wall panels (Url 14,15)

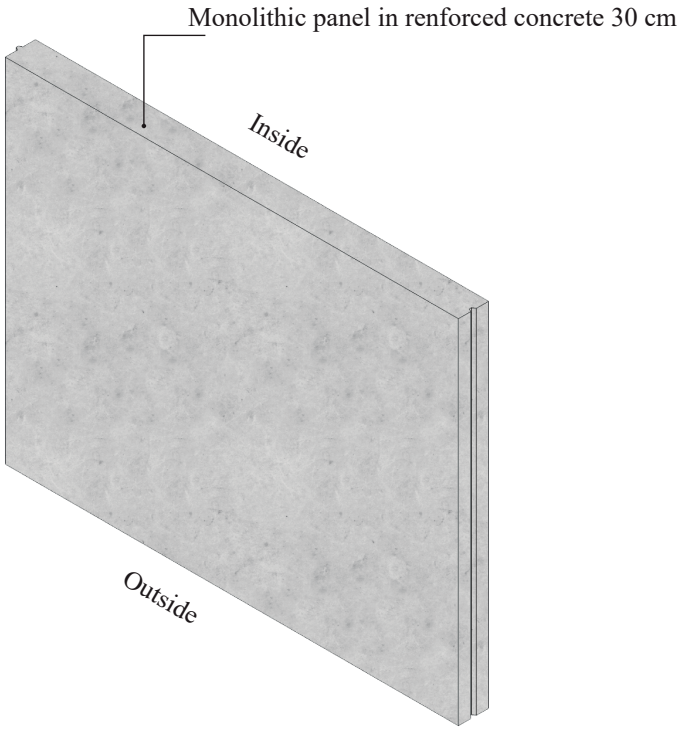
In order to understand better the large variety of solid wall panels available for the design, it follows here below a brief description of some examples, starting from the most traditional ones to arrive to the latest applications. They will report technical performance about thermal insulation. The parameters adopted to compare the degree of panels' characteristics refer to Italian and Chinese codes[1]. It must be reminded that the next examples are valid also as samples of window wall units: indeed, window wall panels can be considered as solid wall panels "punched" by a hole which represents the width of the openings. For this reason, the sequence of layers is similar in both typologies.

1. ITA. Decreto Ministeriale Sviluppo Economico 26 guigno 2015, *Applicazione delle metodologie di calcolo delle prestazioni energetiche e definizione delle prescrizioni e dei requisiti minimi degli edifici*.
CHN. GB 50189-2015, *Design standard for energy efficiency of public buildings.*

- *Traditional applications*

Solid wall panel

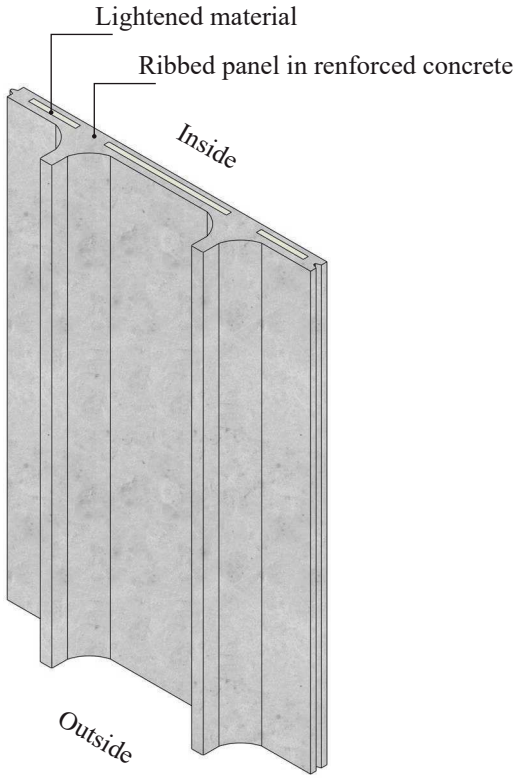
Dimensions: Up to 456x221 cm
Thickness: 30 cm



This typology is characterised by having reinforced concrete as the core material of the panel. According to its properties, the entire use of reinforced concrete confers more structure resistance, without the support of any other layers. The employment of this typology has been used almost in every design application, from residential to industrial and civil constructions. However, this typology suffers from bad thermal and acoustic performance because of the lack of proper insulating layer.

Ribbed panel

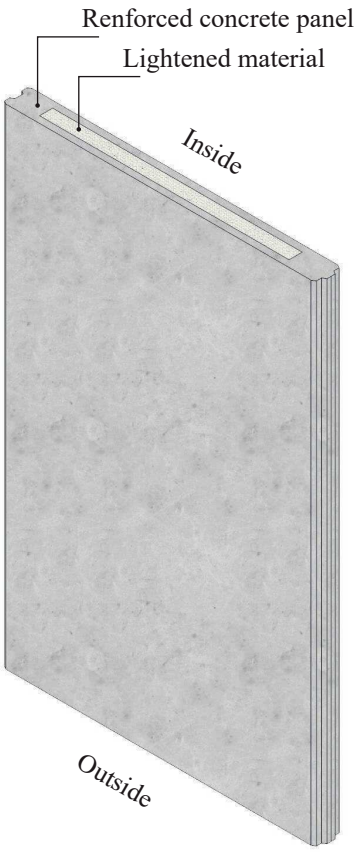
Dimensions: Fixed width 250 cm; hight max 1200 cm
Thickness: 14 cm + 30 cm



The main employment of this typology belongs industrial buildings and warehouses. The idea of ribbed panel starts from the shape of horizontal slabs and roof beams made by pre-stressed concrete: instead of using this element as a slab, the designers decided to apply it as a panel useful for creating the external envelop. Due to its application, this panel is not requested to fulfil high energy saving requirements but simply the minimum demanded.

Lightened panel

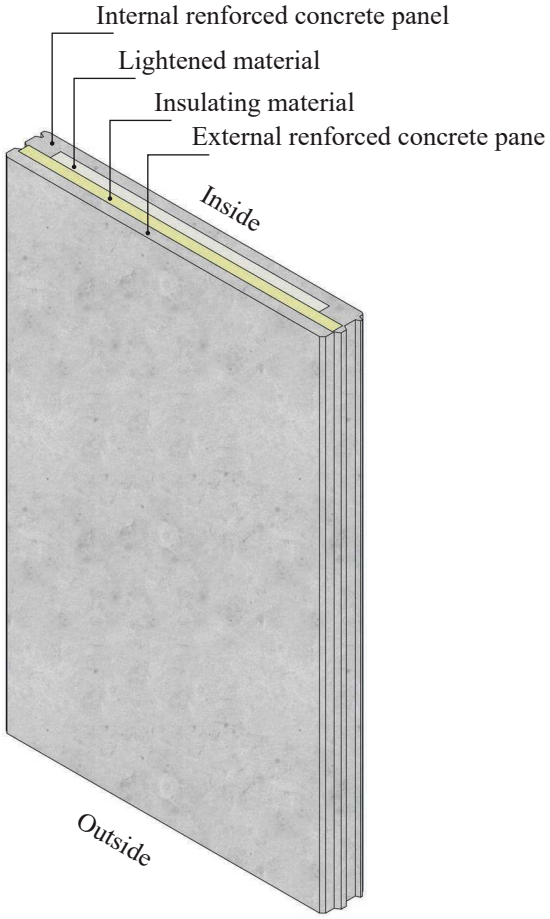
Dimensions: Width: from 125 to 15 cm. Length: from 250 to 300 cm
Thickness: 12 cm



Comparing to the monolithic panels, lightened panels are characterized by a reduced weight thanks to the application of a lightened material inside the concrete layer. In addition, depending on the type of lightened material, this panel is able to assure better thermal insulation. In other words, it represents a solution abled to implement the requirements of comfort and thermal qualities in the building.

Sandwich panel

Dimensions: Lengh 1000 cm; Height 250 cm
Thickness: 30 cm



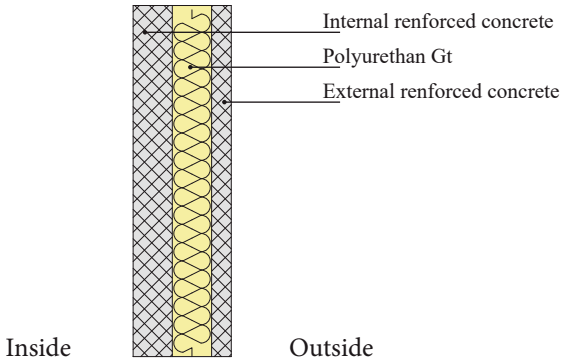
Sandwich panels are the most employed ones in the housing sector. They stratigraphy is mainly formed by an internal structural layer in reinforced concrete and an external non-structural one. In addition, there are two more layers even if it is possible to joint them in one layer only: the first one is the insulating material that can be modify based on the thermal and sustainable performance that the designers want to guarantee. The second one, that is not necessary, is the lightened material. The internal insulation plays a fundamental role in terms of improving thermal and acoustic performance. Moreover, thanks to its lightness, this panels can be delivered and lifted easier inside the construction site. The drawbacks are related to the presence of thermal bridges that hit the joint between two panels.

- *Advanced applications*

The following examples may be considered as the advanced applications for precast panels. This selection has been reported in the Master Thesis “Pannelli prefabbricati per involucro edilizio. Soluzioni alternative” (Pappalardo, 2018) and they have been employed for the realisation of the “Polo Universitario in via Cerola, Milano”. The technical characteristics of these panels have been designed to fulfil the Italian thermal prescriptions (DM 26/6/2015) which are referred to the city of Milan, included in the climate zone E with 2404 heating degree days. The same prescription imposes as maximum wall thermal transmittance value (U-value) 0,26 W/m^2K. Even though the city of Shanghai is characterised by different climate, with 1623 heating degree days (Deyin, Hongwu, Li, Qiang, Xu, 2017), the following examples may be considered as best practises, available currently on the market, employable in the Chinese context as well. From the comparison between the two cities emerges that their different climate location is the reason of the high discrepancy between the two thermal transmittance values. U-value for Shanghai is referred to the Chine code CHN. GB 50189-2015, *Design standard for energy efficiency of public buildings*

Sandwich panel

Dimensions: Lengh from 80 to 320 cm; Height 350 cm
Thickness: 30 cm



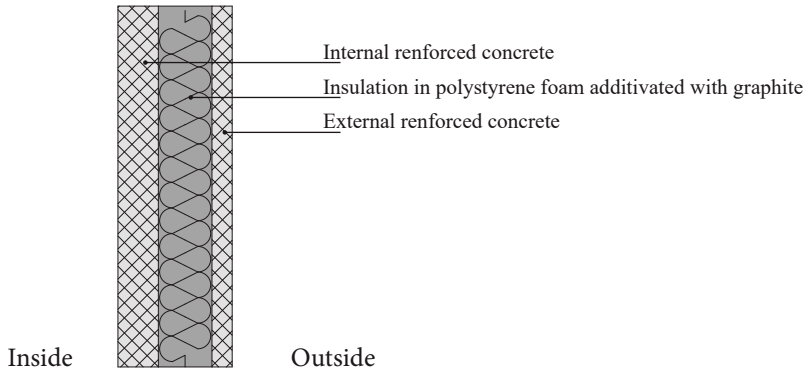
Physical characteristics

N°	From the interior to exterior	d [m]	δ [Kg/m³]	λ [W/mK]	R [m²K/W]	μ -
1	Internal renforced concrete	0,12	2500	1,91	0,06	5-10
2	Polyurethan Gt	0,12	25	0,022	5,22	30-150
3	External renforced concrete	0,06	2500	2,08	0,03	5-10

			Italian code	Chinese code
U	**Thermal trasmittance [W/m²K]**	**0,18**	**0,26**	**0,6**

Sandwich panel with insulation in polystyrene foam additivated with graphite

Lengh from 80 to 320 cm; Height 350 cm
Thickness: 34 cm



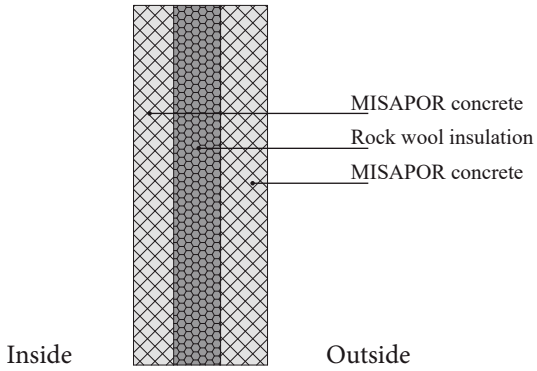
Physical characteristics

N°	From the interior to exterior	d [m]	δ [Kg/m³]	λ [W/mK]	R [m²K/W]	μ -
1	Internal renforced concrete	0,12	2500	1,91	0,06	5-10
2	Insulation in polystyrene foam additivated with graphite	0,16	16	0,029	5,52	30-70
3	External renforced concrete	0,06	2500	2,08	0,03	5-10

			Italian code	Chinese code
U	**Thermal trasmittance [W/m²K]**	**0,17**	**0,26**	**0,6**

High performances Misapor concrete

Lengh from 80 to 320 cm; Height 350 cm
Thickness: 40 cm



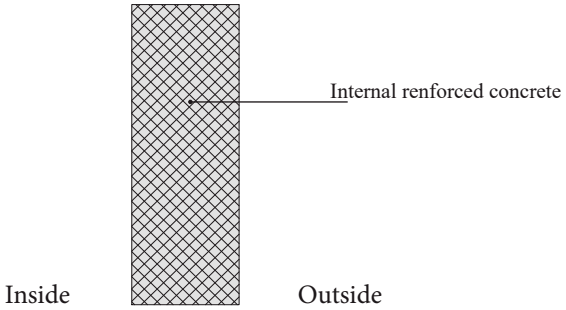
Physical characteristics

N°	From the interior to exterior	d [m]	δ [Kg/m³]	λ [W/mK]	R [m²K/W]	μ -
1	MISAPOR concrete	0,12	120-190	0,27	0,44	5-10
2	Rock wool insulation	0,14	90	0,036	3,89	1
3	MISAPOR concrete	0,14	120-190	0,27	0,52	5-10

			Italian code	Chinese code
U	**Thermal trasmittance [W/m²K]**	**0,20**	**0,26**	**0,6**

Cellular concrete with closed cell structure

Lengh from 80 to 320 cm; Height 350 cm
Thickness: 37,5 cm



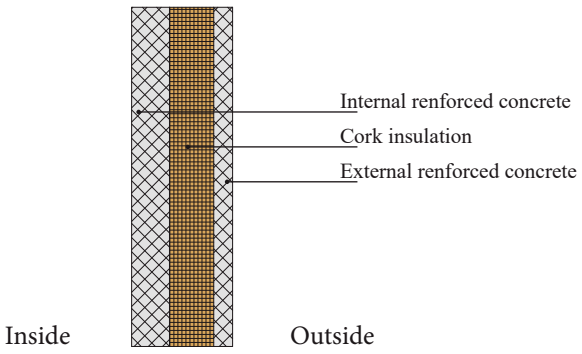
Physical characteristics

N°	From the interior to exterior	d [m]	δ [Kg/m³]	λ [W/mK]	R [m²K/W]	μ -
1	Internal renforced concrete	0,375	500	0,12	3,13	5-10

			Italian code	Chinese code
U	**Thermal trasmittance [W/m²K]**	**0,30**	**0,26**	**0,6**

Sandwich panel with a collection of more sustainable insulation materials

Lengh from 80 to 320 cm; Height 350 cm
Thickness: 32 cm



Physical characteristics

N°	From the interior to exterior	d [m]	δ [Kg/m³]	λ [W/mK]	R [m²K/W]	μ -
1	Internal renforced concrete	0,12	2500	1,91	0,06	5-10
2	Cork insulation	0,14	110-130	0,039	3,50	20
3	External renforced concrete	0,06	2500	2,07	0,03	5-10

			Italian code	Chinese code
U	**Thermal trasmittance [W/m²K]**	**0,26**	**0,26**	**0,6**

Alternative more sustainable insulation materials

Other sustainable inula-tings	d [m]	δ [Kg/m³]	λ [W/mK]	R [m²K/W]	μ -
Wood fiber	0,2	160	0,038	5,3	5
Hemp	0,1	100	0,041	2,4	1,9
Cellular wood	0,2	150-170	0,078	2,6	1,3

- *Window wall units*

Window wall panels are the most employed type of precast concrete unit and, in the past, they were characterised by a large opaque area. This was triggered by the necessity to create a more energy efficient envelope, made from the diminution of windows' width. This enabled to reduce the dissipation of heat during cold seasons and to limit the solar irradiation during the summer periods. It is also preferable in terms of mechanical resistance and stiffness: the opaque concrete part acts as a monolithic element which is more solid due to the absence of additional joints. Nowadays, thanks to the enhancement of insulation properties of the glass, it is possible to design ampler openings without having any problem related to structural considerations. A single panel can be "punched" by one or more windows and this provides close tolerances for window installation. According to the needs of the project, they can be flat or sculptured.

Fig. 1.25 Examples of window wall units (Url 16 -17)

- *Spandrels*

As it has been already shown in cladding modularity section, spandrel panels are horizontal units attached only along the beam and/or column and they are used to divide the strips of glass, one next to the other. They may be flat or sculptured according to the de-

sign purpose. This typology of precast concrete panel is particularly appreciated when the designers want to emphasise the linearity or horizontality of a building's façade, underlining consequently its structural frame. Spandrel panels may define each floor creating an easier pattern and rhythm of the building's prospect. This pattern can be realised by a series of individual units or as one unit of spandrel panels. The aesthetical research has encouraged the designers to experiment new shapes such as those characterised by a vertical tilted profile. This enables the façade to have a unique rhythm and style.

Fig. 1.26 Examples of spandrels systems (Url 18 - 19)

- *Column covers and mullions*

Column covers and mullions are the alternative solution to underline the structural framing across a building façade. Consequently, running vertically up, they became the major visual scheme in a structure. From dimension prospective, these panels may be of the same width of the column or wider. As state in their name, these units often hide the structural columns and may completely envelope them at the ground level. Depending on their arrangement, column covers can have different sizes but they are usually manufactured in single-story units and spanned either from floor to floor. Mullions should be extended as long as possible to minimize erection costs and horizontal joints, always respecting weight and handling limitations.

Fig. 1.27 Examples column covers and mullions

Size, shape and transportation

Panels have to provide a proper design in terms of size and shape because it affects the transportation actions and the in-site construction. There are two main points that have to be taken into consideration: the first one is the possible damages that the structure can suffer after transportation and the second one is the safety measures which have to be followed during the entire process, from the factory to the construction site. Thus, the decision regarding the shape and the size of precast concrete panels represents a delicate design phase. The designers must be particularly conscious of the manufacturing restrictions and the crane lifting capacity. Once in the construction site, the major requirement is the safety carried out every transportation phase in order to avoid accidents involving the project operators or other people. To prevent any unpredicted eventuality during the panels delivery, the operators must be careful especially about width, mass distribution, height and length of the elements carried. Once in the construction site, it must be previously planned the position of the crane and if it can be moved or not. In case of tailing crane, it is crucial to leave the correct amount of space to allow its rotation. The wrong design of panels in terms of shape, weight and size can trigger dangerous swings during the lifting due to the cross-wind action.

Depending on the local legislation, if the transport deals with exceptional condition, it must be permitted by the public institution after the positive rate of any overweight and/or overdimension element. In this case, it is requested the intervention of a load pilot to accompany the transport vehicle. This safety measure is useful to signal the protruding dimensions of the precast concrete elements.

Vehicles and trailers

Nowadays there are several trailers employed to carry the precast concrete elements. A point is that it is not always necessary to use specific trailers such as the A-frame trailer or the purpose-built trailers, but it is allowed the standard flat-deck vehicle, especially for small elements such as prefab stairs or slabs.

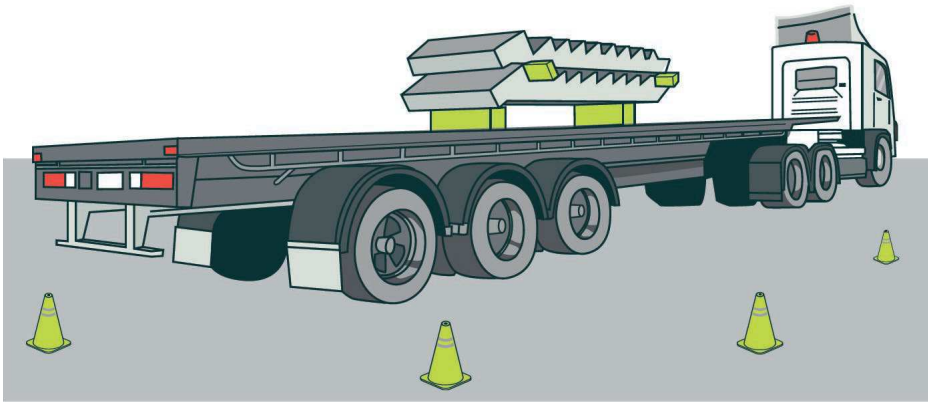


Fig. 1.28 A standard flat-deck trailer (Worksafe New Zealand, 2018, p. 77)

Passing to more accurate vehicles, the most used for carrying precast concrete panels is the A-frame trailer. Although it is simpler than purpose-built trailers, it costs less due to its stiff steel structure upon which the panels are hung up during the delivery. Moreover, there are not any hydraulic items which allow to reduce the maintenance costs. It follows here below same parameters provided by the New Zealand firm Wilco Precast (Wilco Precast, 2018). The parameters change whether the A-flame trail is flat or low:

« Flat trailer

- Maximum allowable height when loaded of 4800 mm

- Maximum panel size 13500 mm x 3150 mm
- No permit up to 4250 height
- Maximum weight 20 tonnes

Low trailer

- Maximum allowable height when loaded of 5400 mm
- Maximum panel size 8800 mm x 4150 mm
- No permit up to 4990 mm height
- With permit 5400 (require pilot, power board, traffic police).
- Maximum weight 18 tonnes »

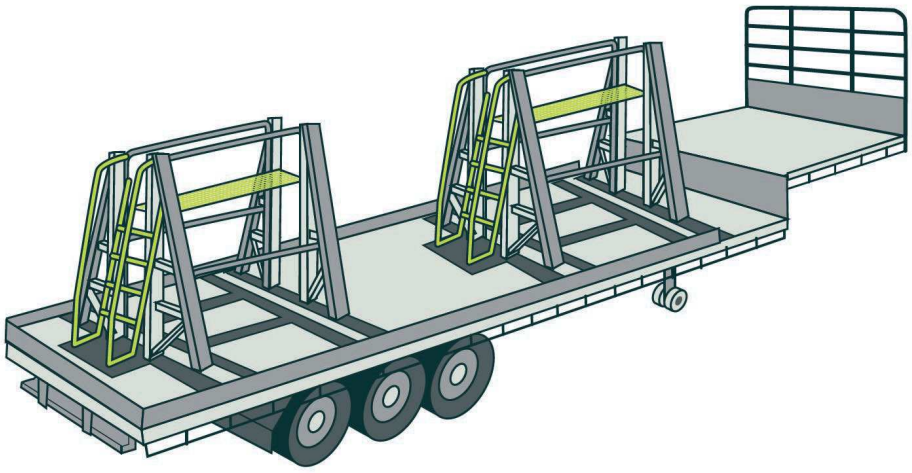


Fig. 1.29 A low A-frame trailer (Worksafe New Zealand, 2018, p. 77)

The most advanced vehicle for precast concrete transport is the purpose-built trailer. Thanks to its chassis design, the main feature regards the low centre of gravity which consequently allows a safer and more stable vehicle.

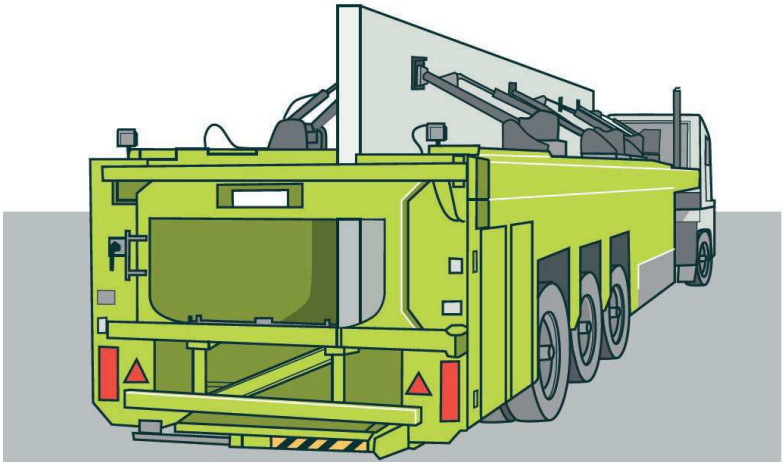


Fig. 1.30 A purpose-built trailer (Worksafe New Zealand, 2018, p. 78)

As well as the type of trailers, it is important to control the way with which the panels are restrained on transport vehicles to guarantee the highest level of safety. First, every concrete panels must be restrained to prevent any fall from the departure until the construction site. Once reached the right location, the elements must be stable after the release and the unloading phases.

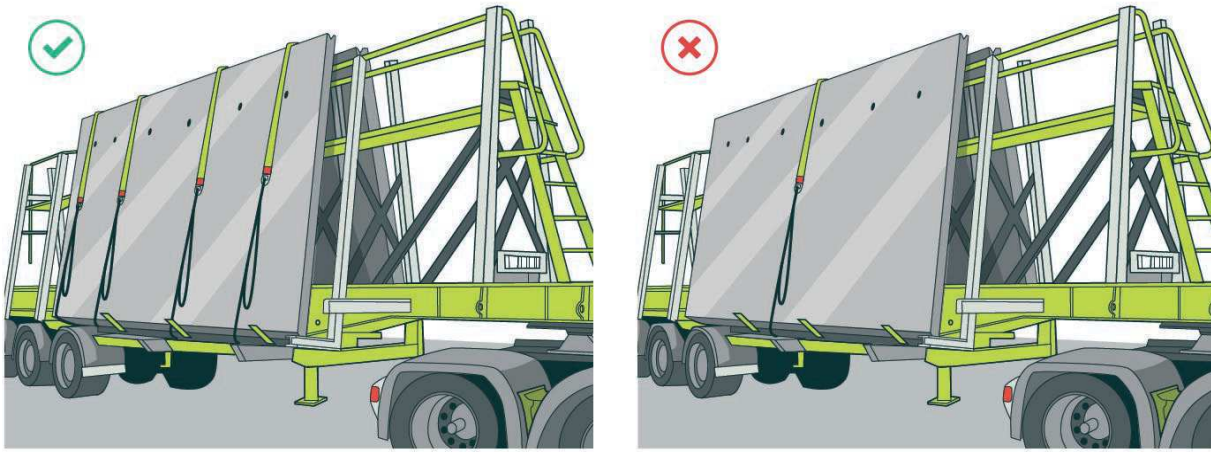


Fig. 1.31 Panels well-restrained configuration (Worksafe New Zealand, 2018, p. 81)

Lifting equilized loads

The panels lifting is the last phase of the transport section. It takes place in the construction site and it needs the same care of the previous operations. It is crucial to follow a precise array of intermediate steps. In order to guarantee the highest level of stability and the balance the weights, the slings must be applied in the correct way: their application enable to avoid unpleasant cracks. It follows the illustration of two possible lifting methods based on the equalisation of the loads in the slings.

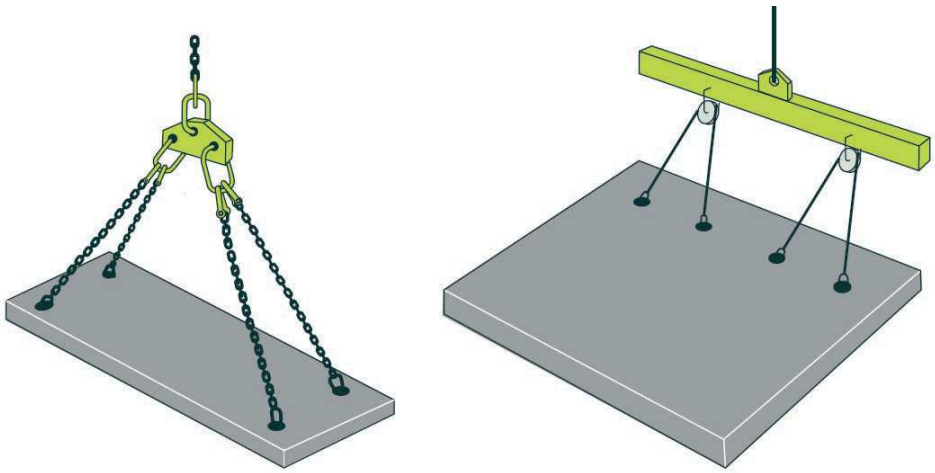


Fig. 1.32 Examples of equalised loads (Worksafe New Zealand, 2018, p. 107)

Some references of contemporary applications

Shanghai Baoye Center

Location: Shanghai, China

Architects: LYCS Architecture

Year: 2017

(Url 20)

Morinoie nursery school

Location: Sendai, Japan

Architects: Masahiko Fujimori

Year: 2017

(Url 21)

Burntwood School

Location: London

Architects: Allford Hall Monaghan Morris

Year: 2014

(Url 16)

2. PERFORMANCE-BASED BUILDING DESIGN (PBD) APPROACH TO GUIDE THE CHOICE OF TECNHOLOGICAL SOLUTIONS

What the PBD approach is and how it works

Performance-Based Building Design (PBD) constitutes the methodological approach that establishes the discipline of Architecture Technology. It is applied during the several phases of the building process and the main scope is to fulfil all the stakeholders' needs to guarantee long-term performances during the building functional life. Thanks to the analysis of the needs, it is possible to identify the so-called user needs (UN), considering the regulatory, cultural, environmental and economic restrictions which the designers must to recognise. Once the needs are defined, the designer has the task to translate them into the performance requirements (PR), identifying the various characteristics that the different parts of the building must have in order to satisfy the UNs detected. As a result, the overall function assigned to the building are then divided in singular tasks assigned to the individual parts of the building itself. These tasks are expressed in a number of requirements to which the various elements must respond. For example, the UN for thermal comfort is translated by the designer into numerous PRs such as thermal inertia control and heat loss through the wall control as well.

The contemporary performance-based approach has its roots since more than 2000 years ago. One of the most important first written proof was embedded in "De architectura libri decem" ("The Ten Books of Architecture") which the Roman author Vitruvius submitted to Imperator Caesar (Becker, 2008). The extract claims «the three departments of architecture, […] the art of building, […] must be built with reference to durability, convenience, and beauty. Durability will be assured when foundations are carried down to the solid ground and materials wisely and liberally selected; convenience, when the arrangement of the apartments is faultless and presents no hindrance to use, and when each class of building is assigned to its suitable and appropriate exposure; and beauty, when the appearance of the work is pleasing and in good taste, and when its members are in due proportion according to correct principles of symmetry»

(Vitruvius, 1 B.C., Book I, Chapter III, section 2).

However, the remarkable novity that Vitruvius presented with his innovative concepts remained only theories until less than 50 years ago. Indeed, during the past centuries, the performance approach adopted was based on «experience-based know-how» (Becker, 2008, p. 2) that was handed down from the previous generation to the newest one. Thus, the quality of construction details and the design solutions was only a technical procure, which planted its seeds in comparing the proposed design and executed details with their standardized prescriptions mandated by regulations, laws and codes. Because of that, there were not any simulation tools to assess the design. Coming up to the recent evolution, the performance concept in building was first defined by the CIB (International Council for Research and Innovation in Building and Construction) W60 Commission as «first and foremost, the Performance Approach is the practice of thinking and working in terms of ends rather than means. It is concerned with what a building or a building product is required to do, and not with prescribing how it is to be constructed» (Lee & Barrett, 2003, p.16). The strength of this statement is represented by the way in which most human activities are planned and carried out. Thus, it allows any person not familiar with the building profession to understand that this is the actual manner employed in building as well.

The last definition was formulate in 2005 within the Final Report of Domain 3 "Design of Buildings" of the PeBBu programme and it outlines PBD as «a process in which performance requirements are translated and integrated into a building design […]. Performance requirements should express the real user needs behind the question for a built product» (Spekkink, 2005, p. 5). This Report is a further elaboration of the 3rd Domain Report "Bringing Vitruvius up to date", that was issues in November 2004. It is the product elaborated by 18 different countries which worked four years over 40 Task Members. The introduction of Performance-Based Building Design shows a standardized way of thinking and operating in design that sets up a conceptual framework which allows the definition of simulation tools and test methods applicable in the building design assessment process. The PBD framework can be summarised by the following steps.

- Recognise the main stakeholders of the building;
- Recognise and define the user needs (UNs)
- Recognise which parts of the building are able to fulfil the UNs recognized
- Translate the UNs recognised into PRs
- Recognise performance statistics, such as threshold values or variables that must be reached to consider the requirement satisfied
- Develop suitable design solutions and assessment tools which are able to verify the fulfilment the performance criteria.

Main Aspects of the Performance Concept

According to the considerations which are emerged in 2005 within Final Report of Domain 3 of the PeBBu, PBD is focused on two crucial characteristics that are reported as they have been stated:

«1. the use of two languages, one for the demand for the performance and the other for the supply of the performance;

2. the need for validation and verification of results against performance targets.»

(Spekkink, 2005, p. 17)

Moreover, as stated in the Report, the demand language is associated to Functional Concept while the supply one is associated Solution Concept. The Functional Concept mirrors the user's needs, so it declares the function which a building should provide in order to fulfil them. On the other hand, the Solution Concept mirrors the technical needs, so it declares the way with which a building could or should be constructed to satisfy the requirements.

Although there are differences of the meaning between the two concepts, the aim should be to identify clearly and meticulously the needs and requirements according to what are the objectives of the project. This is needed to prevent design and construction from being based solely on conjecture and perceptions. Thus, being based on objective aspects, this allows to check whether the solutions adopted by the design process meet the requirements. However, given the complicated relationship between Functional Concept and the Solution Concept, it is difficult to achieve its intended purpose. To figure out this ambiguity, Performance-based approach is an

efficient tool which adopts an intermediate language, "performance language", to match the two Concepts enounced above. Whether from demands point of view functional needs are translated into performance requirements, from supply point of view technical specifications are translated into performance specifications. The first ones deal with the requirements the asset should be intended to use. The second ones are explicated thanks to the characteristics and features associated to the disposed solution. Every translation needs to be validated and assessed through suitable devices: nowadays the information technology tools are becoming more employed thanks to their power and efficiency. It follows a comprehensive chart which sum up the main components of the PBD.

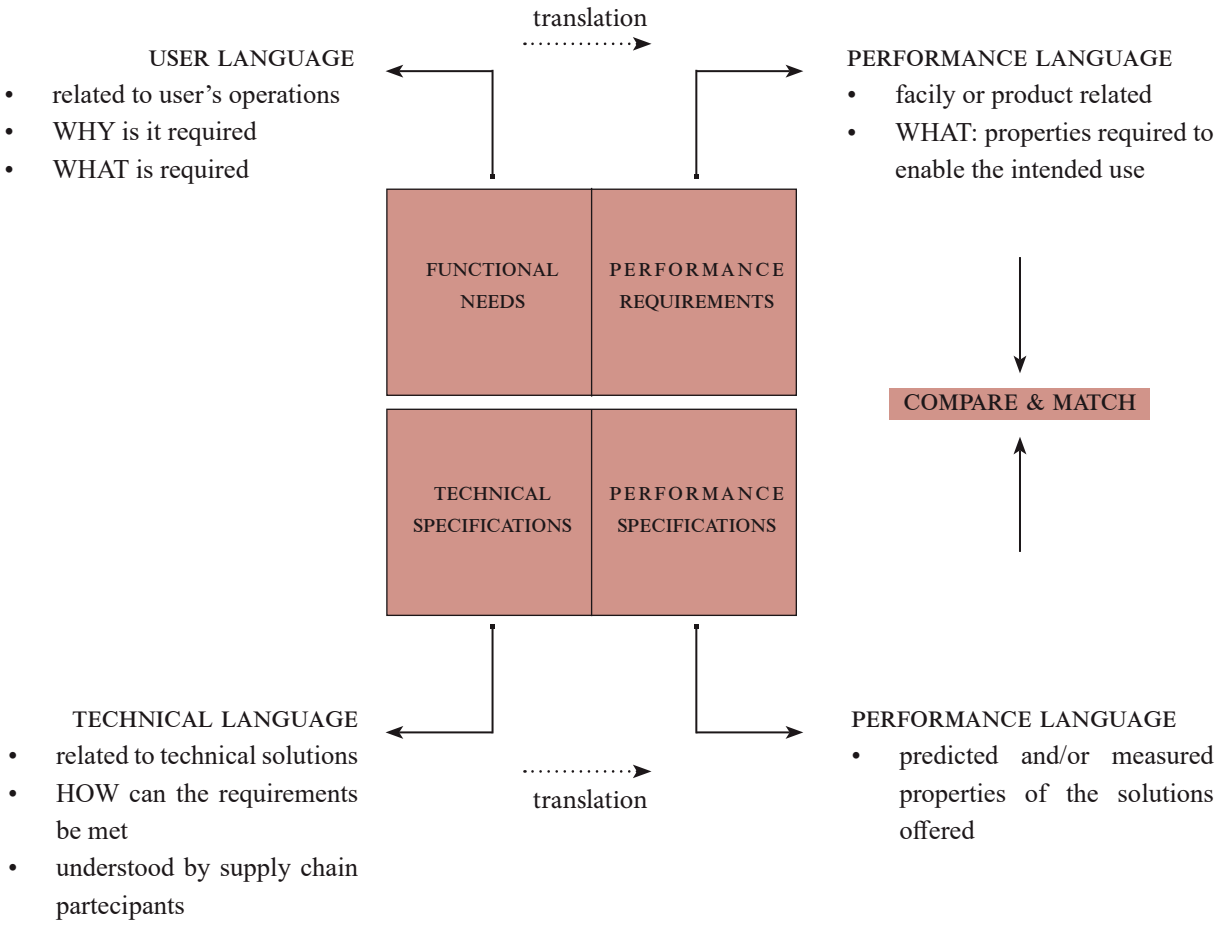


Fig. 2.1 The reinterpretation of "Performance language" scheme (Spekkink, 2005, p. 19)

Different scale level of Performance-based approach

The performance-based approach, applied to a building, can be primarily broken up in different levels of scale according to a reiterated procedure. The highest level is occupied by the "building as a whole" which means the comprehensive scale of the construction. Exactly as it has seen in the previous paragraph, the operative logic is identical for every scale level of the project, starting every time from Functional Concept associated with the demand side which entails a Solution Concept associated with the supply side. Once acknowledged, this method can be replicated for every scale level required.

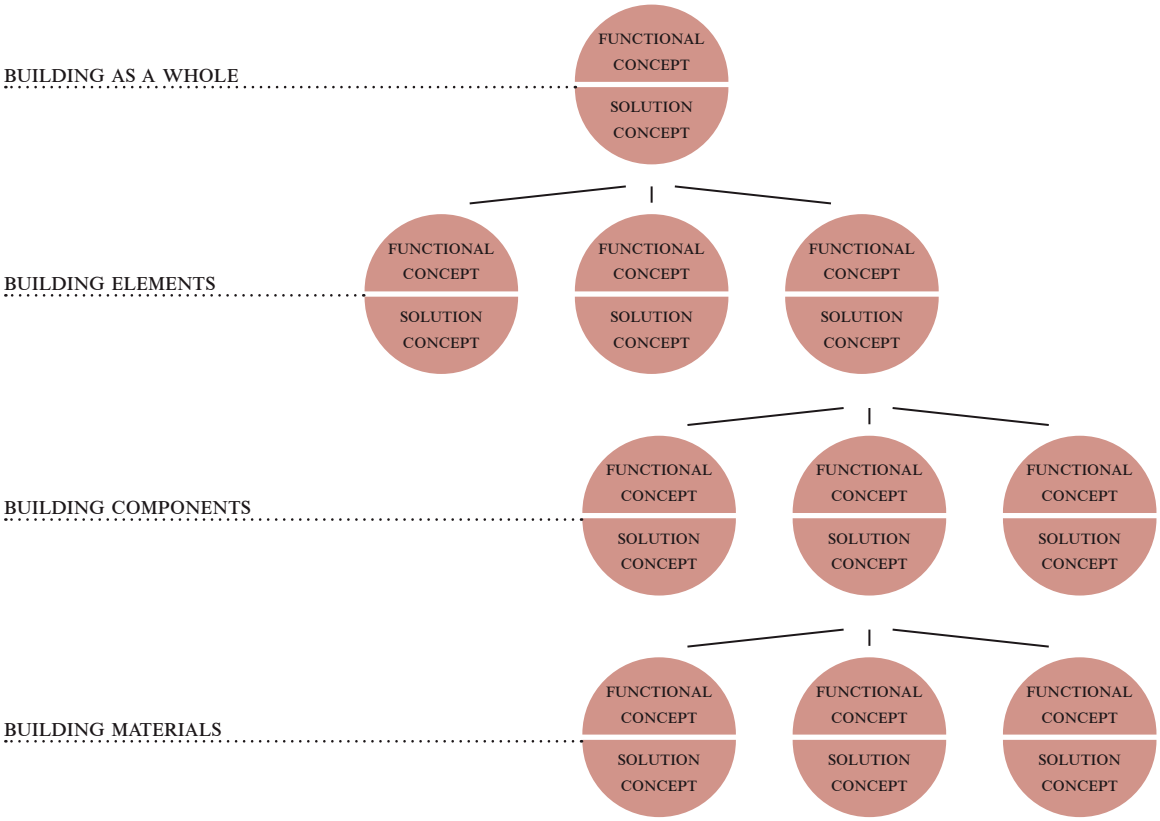


Fig. 2.2 The reinterpretation of "PBD applies to different levels" scheme (Spekkink, 2005, p. 19)

Sustainability aspects

Performance-Based Building Design plays an important role in the sustainable construction approach. This is a part of the performance requirements of the building and it can be fulfiled if the design follows the life cycle logic. It is worth spending a few words to describe the "building life cycle" which is at the heart of sustainable design approach. Building life cycle can be synthesized in six diachronic phases which are typically illustrated with a circular scheme (ISO 21931-2010, Sustainability in building construction. Framework for methods of assessment of the environmental performance of construction works):

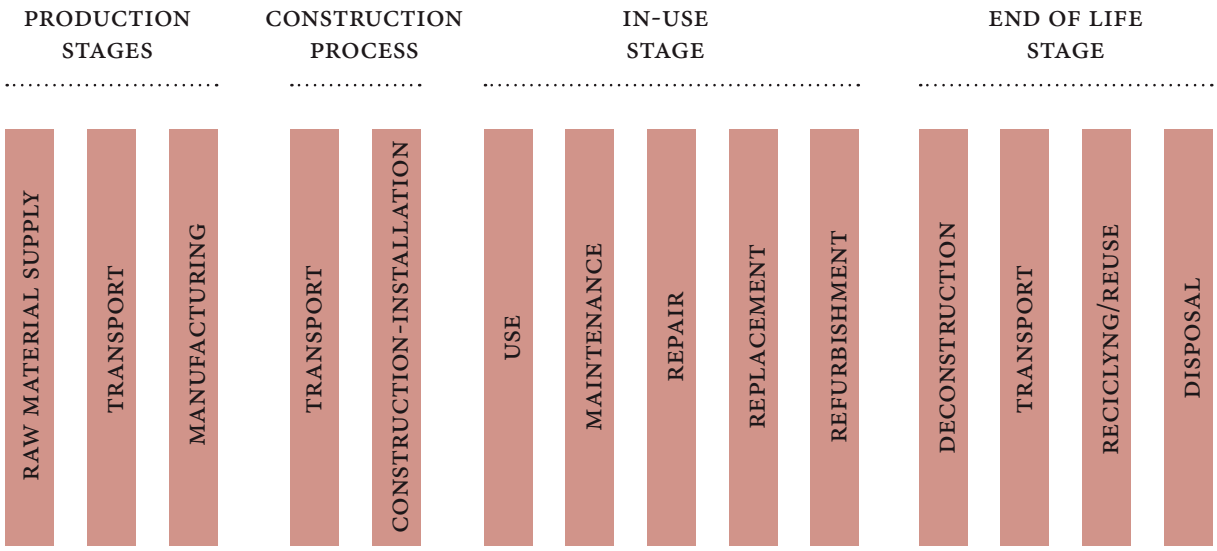


Fig. 2.3 The phases of building life cycle according to ISO 21931-2010

According to the international standard, it is possible to associate each step of building life cycle with the steps of design life cycle and the respective economic assessment tools. There are also three other definitions that are involved in PBD procedure: "service life", "actual life" and "assessment period" of a building component or an entire building.

The first one is defined as the period after which it is more advantageous to replace a component or an entire building than maintaining it for a longer period. It can be also defined as that part of the life cycle during which the asset is able to guarantee the average level of energy efficiency established during the project. Actual life is the period of time from construction to demolition. Finally, assessment period is the expected operating period of a building or a component. Its

prediction is conditioned by physical, functional, economic, technological, social and legislative obsolescence (Fregonara, 2015). Coming back to Performance-based building approach, it is linked with sustainability when it deals with durability assertions. Indeed, the identification of suitable duration of service life can be assisted by the PBD. In addition, the processes used during the in-use phase, which are also required to establish environmental impact analysis and to enable lifecycle cost calculations, are defined by performance requirements.

In the context where sustainability in construction is the point of orientation for all design process, the methodologies developed to estimated service live are provided by international standardisation ISO/TC59/SC17 and in CEN/BT WG 174. The performance of products throughout their use phase as part of the assessed building becomes a key point of interest. This context on one hand requires performance from its parts, while each part may provide preconditions of functionality and performance to other parts, or the entity. At the same time, performance requirements as expressed by users and other stakeholders, may concern the entire building or may be directed to specific elements of performance.

PDB's advantages

- Given that PBD is a method focused on fulfilment of final user's needs, it provides a technical-based way of thinking and working applicable in the design process of many disciplines among which architectural and engineering ones. Performance requirements are the translation of clients' and users' needs explicitly.
- Performance-based approach is a tool of quality at the service of designers and users to reach a better knowledge about the characteristics that the building has or should have. Thus, this method permits to know previously what behaviour the building will adopt during the service life.
- Nowadays, more frequently the states all over the world decide to adopt national building regulations focus on performance-based approach, discarding prescriptive codes. It stimulates the adhesion of the designers to PBD and they have to validate their design solutions with the regulatory framework defined.

- PBD allows designers to avoid incurring into inappropriate answers adopted as a reply of client and user needs. It gives the opportunity to the designers to have a well-organized pattern of work which dictates the understanding and selecting UNs and PRs before proceeding with the solutions development. PBD stimulates thinking about what is behind the question before jumping to conclusions.
- PBD allows professionals to act during the design process in order to integrate all the aspects involved in it. The PBD concept provides to the architects the tools to be the integrator of technical, sustainable, economic, energetic, environmental, well-being characteristics.
- PBD will provide clients and end-users an extra-value of their building thanks to the wider opportunity which this approach gives to the professionals to enhance creativity and innovation in the design and building process.
- Performance-based approach allows to establish a better relation between contractors and suppliers, optimizing aspects of innovation and cost control.
- PBD leads to a more responsible environmental behaviour adopted by industry sector. This is caused by the fact that environmental protocols are mainly performance-based.

PBD's drawbacks

- According to the members of Domain 3 the main obstacle for further development and implementation of PBD are the traditional culture of the building process, based on the prescription approach.
- Many professionals believe that the most important quality aspects of buildings can not possibly be translated into performance specifications.

Main stakeholders

The following main stakeholders are selected according to the research paper "Fundamentals of Performance-Based Building Design" by Rachel Becker.

- *Users*

  They embed the inhabits whom settlement in the building is characterized by a long-term duration, but also maintenance personnel, repair workers, rescue teams and guests, who visit the building more sporadically. The majority of the UNs are due to the fulfilment of end user' requirements, especially related to their well-being and their activities. The most common user needs are accessibility, safety, security, serviceability, health, comfort, ease of maintenance and durability. It is important to underline that in this group are included also general public; the building may create several impacts on it in particular in terms of noise, shadows, resource depletion and energy consumption.

- *Entrepreneur/owner*

  Owners or entrepreneurs who maintain the ownership of the building during its service life are the principals end users. It is possible to define different roles that owners can have in the construction process: first, they can be the promoters of the project. This fact boosts the use of more efficient and reliable technological solutions which allow to enhance the performance levels compared to minimal levels required by regulatory framework. Thus, these solutions enable meeting the most significat needs at a minimal cost. An example could be the choice of insulation with a more elevated thickness or more accurate manufacturing practices such as the correct dimension on the reinforced concrete cover that improve durability. The second scenario is when the final purpose of the entrepreneur is to rent the property. He will not pay so much attention to end user's well-being and comfort, rather than ranting incomes and the continuity of the in-use performance without maintenance.
  The third case takes place when the final goal concern to selling the building after its completion. Entrepreneur will basically be warried about optimizing the profit whereas this

will go to the detriment of the well-being of the end users, energy consumption, long-term performance and durability.

- *Design team*

  It embeds architects and engineers and the comprehensive group of professionals who are involved in the project. It is imperative that design professionals adopt the performance-based way of thinking and working in order to demonstrate that their design solutions satisfy at least the legislative requirements. Thanks to the employment of PDB, it is essential that designers move towards "sustainable design" which can deal with both engineering and architecture aspects. According to engineering prospective, sustainability concerns energy efficiency, use of specific materials and correlated performances, detailed technologies, durability and performance of components or systems. On the other hand, according to architecture prospective, sustainability is also linked to environmental, social and economic aspects of materials and technologies. Thus, the balance between design and sustainability has to be found in the cost component. This represents the limitation on which the alternative solutions are defined; for example, the different solutions are concentrated in technical solution packages with different performance and cost levels and the preferable choice is selected by the cost optimal approach.

- *Manufacturer*

  It considers all productors who are involved in the production processes of building materials, components, and building systems. The regulatory framework accepts or refuses product properties comparing them with the standards and this allows to exchange information between manufacturers and the other stakeholders. Every product is categorized by a specific set of properties and they are selected and combined to obtain the suitable in-use performance, depending of the requirements involved in the design process. New products are assessed by performance test methods which permit to simulate their final performances.

Part II – The context

3. CHINESE REAL ESTATE MARKET AND THE USE OF CLADDING SYSTEMS

The Chinese real estate market is a very tough topic due to its complexity and the numerous players involved. This paragraph wants to summarise the key aspects in a synthetic way avoiding elaborated economics contents.

During the Maoist era, the property duty and the houses assignment were managed by local institutions directly controlled by the National Congress (Candido, 2018). This pattern started to change during the 1980s: thanks to the revision of the Constitution occurred in the 1988, for the first time was introduced the difference between the property duty and the use duty of a land. So, people need to buy the use duty of an estate signing a contact with the local administration: the period of use depends on the function of asset and in the case of residential use the concession lasts 70 years (Candido, 2018). Thus, the possession of a property pass through the right of use it.

Having said that, the exponential growth of the Chinese real estate market has begun in the early 90s. The policies of liberalisation triggered a significant urbanisation, boosted by a massive immigration from the country to the city. People from rural countries were attracted by the new opportunity of life improvement that the urban areas was offering to them. For this reason, the housing demands rapidly increased (D'Andrea & Parteners, 2019). To tackle this issue, an enormous group of investors and construction enterprises, local or international, were involved and in short time they were able to build millions of squared metres sacrificing the quality of the final products. This scheme was necessarily supported by the Central Government and the People's Bank of China which released huge and easy financing to the constructors (Riccardi & Wang, n.d.). The ease of the access to the credit has brought about the interest of international companies which saw the Chinese real estate market as an unmissable opportunity for their business. Hence, shortly, the market moved from a condition of buildings shortage to a saturation. However, taken into account the impressive amount of money and companies implicated, the expansion of the cities continued unstoppable. Thus, the entire Chinese building market has

become the subject of the biggest speculation which still lasts. Moreover, once the economical conditions of people started to improve, they invested their savings in the construction sector, given that its solidity and low risk exposition. This fact contributed to augment the rate of mortgages got and to undermine the already weak financing system (Timpone, 2019).

Exceeded brilliantly the 2008 global crisis, the first signs of implosion were recorded in 2016. According to Shanghai E-House Real Estate Research Institute, the prices of the houses in Beijing, Shanghai e Shenzhen increased dramatically recording a "price to income ratio" equal to 23,2 which means that the cost of a squared metre is 23,2 time higher than the family revenue (Riccardi & Wang, n.d.). In order to face the higher costs, the instant consequence was to increase the demand of bank loans; this at the expense of the public dept that has reached quickly the 270% while the economic growth is steady reducing. However, nowadays, the house prices seem that not only to arrest itself but are continuously rising. Considering that about the 25% of the Chinese GDP is due to the real estate, it is very challenging for the Central Government to handle the situation. The measures acted to contain the collapse deal with the establishment of a maximum prices and the payment of property tax. The speculation has brought also physical and social consequences: currently in China the so-called "ghost cities" are getting common. Indeed, there are 65 million of empty apartments equal to 22% of the total. It is the highest trend in the world (Colarizi, 2019). On the other side, it is becoming harder for a wide number of families afford the expensive costs of the megalopolis, causing the new migration towards smaller cities.

Whether an economic and political solution results to be complicated, from architectural and engineering point of view it is possible to re-establish a competitive building market. It could be applicable if the projects were focused on the fulfilment of the stakeholder needs and to enhance sustainable approach including costs, energy, resource savings. The technological systems which can meet these requirements are the precast concrete panels. Thanks to their key advantages, they have been already employed in most of the high-rising buildings construction, making China one of the larger productor and user of precast concrete construction elements in the world. Their serial production allows to reduce the final cost, obtaining a handy, flexible,

standardised, efficient and easy to be shipped and installed elements, able to fulfil the current requirement of cost and time saving. However, as reported in “2017 China Precast Concrete Industry Development Report”, despite the large investment in the prefabrication sector, there are important concerns about the quality and the sustainability of the precast products due to the low-level of production plants. This is caused by the lack of professionals, managers and workers sufficiently experienced to tackle with technical and executive tasks (Cihie, 2017).

4. CHINESE STAKEHOLDERS NEEDS

4.1 The needs analysed

After having taken in account the most comprehensive background of the prefabricated cladding system and the precast concrete panels, according to the logic of PBD approach, the first crucial step deals with the identification of the principal stakeholders needs. As already mentioned before, the stakeholder needs selected and analysed are settled in the Chinese context and they have been deepened employing both academicals resources and real meeting experienced during the stay in Shanghai. Moreover, the joined work with the research group of Tongji University and the Italian professors has led to a focus on the most relevant needs which could have affected the final tool design. It is important to underline that these needs are associated to the different stakeholders and for this reason their contents change according to the stakeholder class analysed.

The needs considered are safety and security, wellness, usability, appearance, compatibility, management and environmental protection. Safety and security can be considered the same need: it deals with the safety to unpredicted events caused by the external environment such as earthquakes, floods, volcanic eruptions. At the same time, this need is connected to the prevention against unexpected incidents referred to the building operating life such as fire, gas leaks or break-in. Having considered a large number of stakeholders, safety and security are also referred to the workers conditions in the production plants and in the construction sites. The need of wellness is extremely important in the Chinese context and it regards the whole aspects related to the comfort. It encompasses not only the comfort inside the building or production places (acoustic and thermal comfort, indoor and outdoor air quality and the environmental pollution) but also psychological comfort which concerns the freedom to operate in the construction sector without any impositions and pressions from third party. Then, it follows usability: it is related to the importance for the stakeholders of using the general building considered in the appropriate way. The spaces should be accessible and fit the activities defined for them. The next need analysed is appearance and it regards the way how the

stakeholders perceive the building and spaces considered. For a group of stakeholders this need has additional meanings such as the need to appear transparent in the decisional processes or improve the appearance of the design solution in order to get the design team more competitive. Compatibility generally means the necessity to connect different elements efficiently and respecting the core of the different parts. In this analysis it essentially deals with the coherence between what was approved in the executive project by the design team and what realized during the construction phases. The management is related to the planning and the organisation of the different activities referred to the design, construction or maintenance of a building. The last need considered is the environmental protection which is strongly felt in the current Chinese society and it regards the adoption of new strategies to strive the global pollution.

4.2 Users

Safety and security

- Because China suffers from frequent earthquakes actions, people want to live in safe and solid buildings and wish that their houses will be available after the quake, reducing dramatically the amount of damages. The earthquakes threat is strongly felt in Chinese regions due to the long history of these devastating natural phenomena. Nowadays China is currently 10th in the world for probability of a 6.5 magnitude earthquake (CRED EM-DAT, 2015). The most at-risk areas include West, South-West and South parts of the country, especially the most recurrent activities are recorded in Tibet, Sichuan Province, Yunnan Province, including also Taiwan (Runqiu & Weile, 2011). China counts three of most catastrophic earthquakes which occurred in the human history: the most devastating one took place in 1556 in Shaanxi Province, where it was estimated that more that 800000 people lost their lives. The third and the fourth happened respectively in 1976 in the city of Tangshan, Hebei Province, where 250000 were the people dead, and in 1920 in the city of Haiyuan, Ningxia Province, where the victims were about 200000. The last most tragic seism took place in 2008 in Sichuan, the third Province in terms of population, which was struck by 7.9 magni-

tude earthquake. At least 69000 people died. The area of the city of Wenchuan under which the epicenter was located was almost destroyed and the tremors were felt as far as Beijing and Shanghai, respectively, 1500 and 1700 kilometers away (George Pararas Carayannis, n.d.). After the quake the building standards were revised and hardened. The Chinese Earthquake Administration (CEA) constantly gathers data in all provinces and works to ensure the safety of citizens. It provides some predictions which can help to determine the moment and the place of one potential future event, although they are subjected to imperfection and unpredictable behaviours. Cities such as Shanghai and Beijing are classified as low risk area even though they were run over by earthquake swarm generated in the several faults dislocated across China. Historically, the large parts of victims were provoked by the poor infrastructure and technologies employed in constructions. The majority of traditional houses is erected using mud bricks which are known to be fragile and not very elastic. However, in the last incident also the reinforced concrete buildings shown significant collapses and loss of bearing properties.

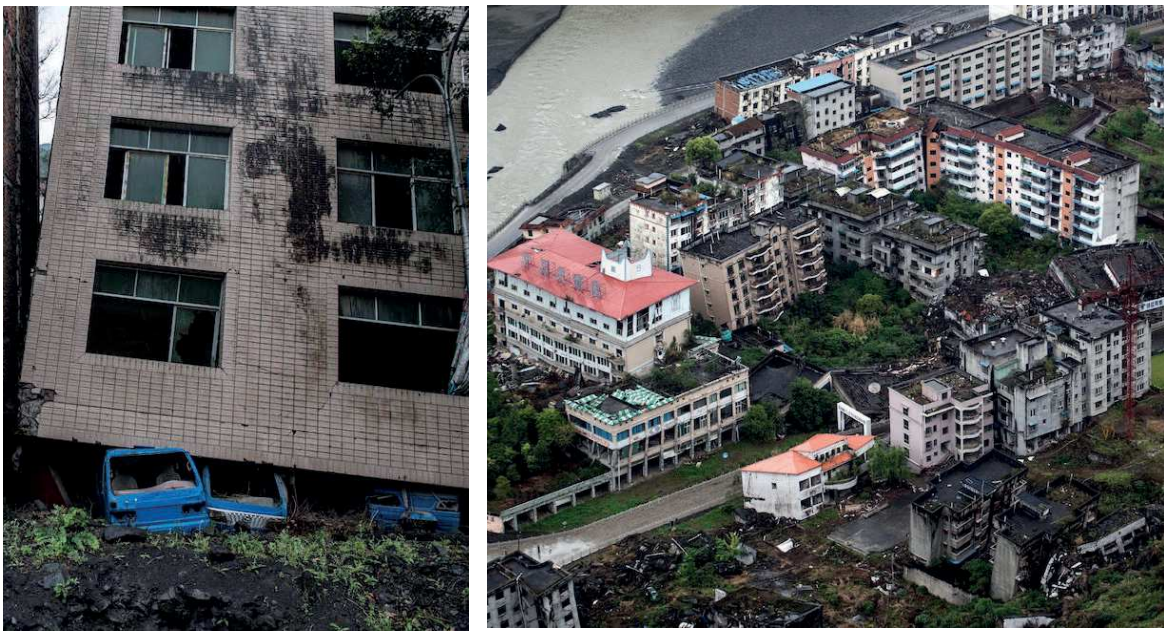


Fig. 4.1 The tragic consequences of 7.9 magnitude earthquake in Sichuan Province, 2008 (Url 22-23)

- Users want to be safe against fire that can develop inside or outside the building. If historically the cause of fire was due to the use of flammable building materials, such as wood or

rice paper, today it is mainly sought in electrical and heating systems. In terms of residential buildings, gas, oil and coal stoves are still widespread for heating but dangerous for both indoor air quality and the risk of fires. On the electrical system front, especially those related to the electrical distribution network, they are characterized by a disorderly branching that often lap dangerously the facades of adjacent buildings.

- Users require to be protected against natural and anthropic disasters such as floods, tornados, hurricanes, earthquakes, landslips and blasts. According to the CRED EM-DAT (CRED EM-DAT, 2015), storms and floods are the most frequent phenomena which occur across China. Although earthquakes are the most lethal natural disasters, floods have the most significant impact over the economic damages and rank second in terms of mortality.
- Even if it is not a very felt issue, it is important that users feel secure in terms of housebreaking. China, especially the big city as Shanghai, Guangzhou, Shenzhen, has a remarkable low rate of crime which implies breaking into houses. This is assured thanks to the police organization and the high-tech means of surveillance.
- Although the big efforts put in place, users always cope with the risk of harmful substances contamination. The causes are multiple and attribute to the energy, transport, building and agricultural sectors. In building field, the exposition of unhealthy indoor materials, the erroneous installation of components, the uncontrolled manufacturing process can affect the users well-being with important consequences on their health.

Wellness

- To improve the indoor comfort, it is necessary that people can live in an appropriated acoustic and thermal domestic environment. It becomes more challenging seeing the size of Chinese megalopolises which are consequently characterized by an enormous concentration of population. Referring to Shanghai, it is the second most populated city in China, with a population that exceeds 35 million people. Since 2000, the financial and innovation leadership has boosted the growth of population, peaking at 37.53% (Rolando Y. W., 2019). As a result, Shanghai has been planned following two developments: the horizontal one and the vertical one. The first development concerns the impressive expansion of roads and motorways, that

now count more than 1500 km dislocated from the core until the suburbs of the metropolis. The second development is related to vertical direction of the city with its buildings witch tent to reach the sky. In 2011 there have been over 21000 buildings with an average height between 11 and 15 storeys. The over 30 storeys have been 1066 (Citterio, 2014). The result of that is resumed in large avenues with permanent heavy traffic noise and a considerable urban canyon effect.

- The climate plays a crucial role in terms of users' needs. Due to its enormous territorial extension, the different areas of China are characterised by various typology of climate. Temperate continental climate is typical of north-western regions whereas monsoon zones are recorded in the East, Middle East and North-East. Low temperature and cold climate are frequent in the West of China, because of its abundance of mountains (Runqiu & Weile, 2011). Regarding Shanghai, the weather is typically cold during winter time (temperatures between 0°C and 8°C, relative humidity upper 70 % and rainfall of 52,8 mm in January) and hot during summer time (temperature between 26°C and 32°C, relative humidity from 80% and rainfall of 154,5 mm in July).
- Residents are also worried about air pollution. Indeed, because of the big development of the major cities and the extended consumption of coil to yield electricity, the air appears to be polluted for several days per year. So indoor air quality must to be as much as possible health and clean. The bad air quality is considered as the price which China has payed to benefit the economic wellness. The economic transformation which has taken place in recent decades has profoundly changed the Chinese landscapes. The increase of air pollution is directly linked to the economic reforms taken by presindent Deng Xiaoping in the 1978: the stanning economic development, responsible of the economic well-being, has required a huge exploitation of energy and unrenewable resources. Aware of the issue, Chinese government has acted many laws and regulations since the 1970s. Moreover, in 2012 has been introduced the Air Quality Index, the essential tool which provides a series of important indicators and pollutants measurements. The most concerning are PM10 and PM 2.5 because they can bypass the nose filter and so trigger cardiovascular and respiratory diseases. Despite the big effort of Chinese Government, there are still 460 million people who live

in cities affected by critical pollutants concentration produced essentially by steel and coal industry. Additionally, the most advanced cities, such as Beijing and Shanghai, are able to face with pollution more efficiently thanks to larger financial support from central government.

- The water supply is another point since tap water is classified as not really safety if it is drunk without a filter. In the case of Shanghai, Huangpu river is an important source, supplying, after being treated, almost the 20% of tap water (Health and safety in Shanghai, n.d.). In 2014, the Ministry of Environmental Protection produced an environmental report warning that about 20% of the country's population, 280 million people, do not drink drinking water with high risk for their health (Mo, 2014). Many important scientific journals have denounced the presence of arsenic in groundwater, successively used as the reserve of drinking water for almost 20 million people. As represented in the map below, the most in danger territories are western rural areas. Obviously the impact on the inhabitants health is ravaging causing lethal diseases. Another issue related to the water is its shortage: the China's morphology does not allow to have a homogeneous distribution of water across the Country. The largest presence of exploitable water is in the South regions whereas the others are suffering from an increasing desertification (Bruno, 2018).

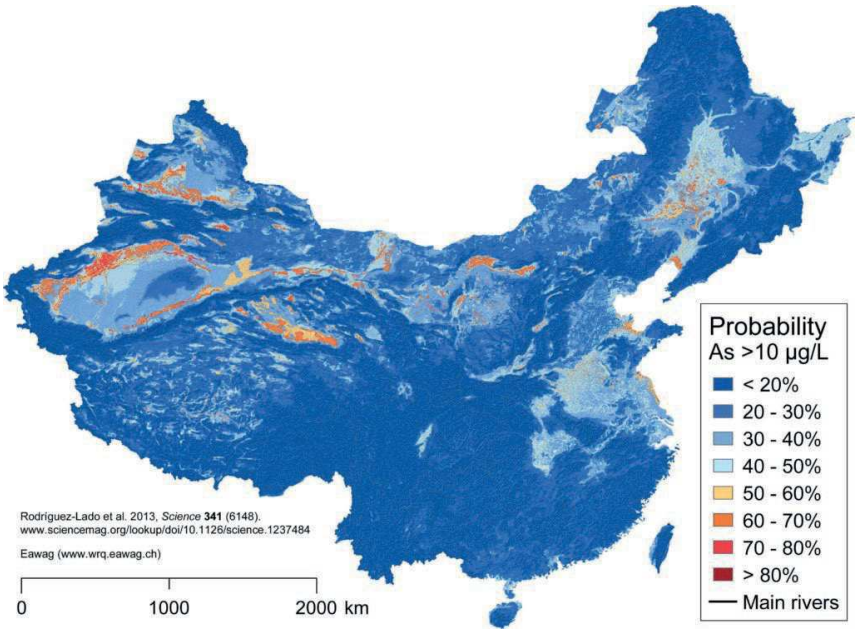


Fig. 4.2 Probability of groundwater arsenic contamination in China (Url 24)

Usability

- They require general better housing standards, according to the current spreading of economical wellness. Since 1990s, Shanghai, as the rest of China, has seen a quick rise of its inhabitants. However, this rapid increasing was not supported by the appropriate satisfaction of housing demand, given that the local government was still based on socialist construction laws. In order to overcome the issue, thanks to new international treaties, the Country passed from planned socialist housing market to a free housing market, allowing foreign investors to bring into China Western knowledge in construction and standards (Citterio, 2014). This process gave the opportunity to modernize the historical practises which were applied both from urbanist side and building one. These measures enabled to exceed the previous building typology such as Lilong, which was the combination between Western row-house layout and the Chinese tradition one, or Work-unit compound, which was the symbol of the socialist regime popular housing, or even Urban villages, which has condemned many low-wage people to live in this sort of ghetto.

  The new parts of the city under construction were characterized by high population density due to the scarce availability and high cost of the construction lands. For this reason, starting from the inner area of Shanghai, buildings with variable uses began to be designed according to towers building typology. Even if the conspicuous designs' efforts, these new high-rise constructions look essentially the same, distinguishing from the other due to their details on the top which make them extravagant. However, the number of high-rise buildings is constantly increasing passing from 799 units in the 1990 to almost 50000 building with an hight between 24 and 100 m in 2017 (Barr, 2019).

  Indoors volume must be ampler especially in terms of storey's height, given that traditionally the dimension between two slabs was often reduce due to related costs. The gradual enhancement of square meters per capita took the first steps during the reforms period, after 1979. If the initial rate reached 4,4 square meters per person on average, in 2000 it showed a gradual increase up to 11,8 square meters. The current target consists in assuring 32 square meter living-space per person by 2020 (Citterio, 2014).
- It is spreading out the need to eliminate, or at least reduce, the architectural barriers which

characterize indoor and outdoor spaces. Indeed, until few years ago, it was widely recognized that people who suffered from disabilities were discriminated and forced to face with daily difficulties in moving around the cities. Thus, there was not sensitivity to design building and public spaces accessible for everybody.

Appearance

- Thanks to the improvement of social and economic status, new social classes are striving to have their own new houses the most possible luxurious and opulent, desire encouraged by global advertising which is strongly rooted in modern China. This is supported by the fact that the Chinese pattern of the city disappeared almost entirely during cultural revolution, marking the loss of a specific Chinese model (Citterio, 2014). It still survives as a revocation in new commercial areas, which are generally built referring to traditional Chinese style. Hence, in order to expire their project, very often design groups take as a reference the North American post-modern architecture, precisely the model of Manhattan, or contemporary Japanese style. Furthermore, also the European classicism was taken as an example. In fact, after a long hibernation during the socialist era, Large part of the French Concession in Shanghai, developed in the 1920s and 1930s, returned to life with the restoration of historical buildings with the addition of art deco apartments and western boutiques. The new classicism was not limited only to private homes, but also offices and government buildings.
- From a cultural point of view, people like transforming their places according to their practical needs or just to enjoy it. They are used to demolish walls and change the use of the rooms in which they live.
- Users want that their new apartments are more comfort than in the past: inside of them they want well-equipped kitchens, a dining room where people cook and eat food, technological entertainments in the living room and bathtub in the bathroom.

Management

- Users are reluctant to spend money for unscheduled and extraordinary maintenance. For this reason, they want efficient houses and only regular expenditure to face with. Hence, it is necessary to use long-durability materials and components.
- The house management is radically changed after the socialist era, and in today's day inhabitants demand that the economic, functional and maintenance management is carried out by private professionals or administration companies. This is why, before housing reform launched in the 1980s, housing market and management depended only by the regime. For this reason, free market and private investments were abolished and persecuted. Therefore, housing was designated as a social rather than an economic sector.

4.3 Entrepreneur/owner

Safety and security

- In terms of safety and security, users share a lot the aforementioned aspects with entrepreneurs/owners. They want to feel safe against every environmental threat such as earthquakes, fires, harmful substances contaminations, floods, landslides. Also, anthropic dangers must be reduce that means low criminality and political stability. If they are secure, especially when the entrepreneur is at the same time the owner, they are more disposed to invest in good quality settlements given that the risk is limited. These instances are becoming increasingly important when the entrepreneurs invest in construction sector buildings destinated to be rented. As they seek the most conspicuous income from their business, they must operate in a risk-free ambience in relation to economic and operating aspects.

Wellness

- Exactly as the users, entrepreneurs/owners are care about indoor, acoustic and thermal appropriate comfort, indoor and outdoor air quality and the environmental pollution. Talking more specifically about the entrepreneur's side, they are more engaged with wellness de-

mands when the final purpose of their business is to put the building in the market. In fact, since the renovation of Chinese codes about energy savings and domestic wellness, they look for more efficient technologies to be more competitive in the construction market. Especially in wide city as Shanghai, the prices of the new-construction buildings are constantly increasing both the saturation of the inner part of the city and the growing international demand of housing. For this reason, entrepreneurs who aspire to rent or sell new buildings require to imply in the design higher performance features, such as material and systems, to intercept the latest standards in terms of well-being.

Usability

- Owing to the fact that Shanghai is establishing itself as a political and social developer megalopolis in China, it is always fundamental assuring the widest usability. Entrepreneurs request spaces accessible for people of all age groups without distinctions. Always for be more competitive in building market, the application of more usable spaces is highly requested by entrepreneurs, given that the change in users standards and the foreign citizens who are interfacing with Chinese real estate.
- It is becoming more frequent that Chinese entrepreneurs/owners refer to Western standards in term of design of space without architectonical barriers. Owners request room where people can move inside safely and healthy, thus devoid of sharp edges, steep steps and equipped with ample windows and openings.

Appearance

- In an increasingly saturated market with international standards, entrepreneurs rely heavily on the appearance of the building and require increasingly innovative and classy solutions. According to the appearance issue, the demands change depending on the area where entrepreneur decide to invest: it is progressively trendy that the buildings located in the downtown areas of the city, which generally preserve a certain architectural heritage of European origin, tend to re-propose the reinterpreted characters in a modern key. For this reason, the

demands are focused on the use of fine finishes, employing high quality materials such as stone or ceramic. On the contrary, in newly urbanized areas, such as along the banks of the Huangpu River, entrepreneurs are more oriented towards a more contemporary and high-tech style as there are mainly service buildings and offices.

Management

- Entrepreneurs/owners require a rational and well-organized management of all life cycle project's phases, from the initial briefing up to the end-of-life and disposal. Management needs to be efficient, hence it is requested that a singular or a group of professionals should be designed to take charge of all the practises of organization tasks. Especially in big building, entrepreneurs/owners are worried about the rising costs and unpredicted expenditure which can occur during the functional life of the construction: to avoid them, they often rely on project managers working from briefing phase to construction one (this is called project construction management), asset, property and facility managers working during use-maintenance and adaptation phases (this is called asset, property and facility management). The suitable management allows to obtain high-quality buildings and to extend their durability with certainty of reducing the economic effort for all stakeholders.
- Since China is the 87th corrupt nation out of 180 countries, according to the 2018 Corruption Perceptions Index reported by Transparency International (Trasparency international, 2018), entrepreneurs/owners do not want to be involved in bribery logic which could compromise their investments. They feel the necessity to not be subjected to the will of criminal organizations which can considerably compromise the successful outcome of the project.

Environmental protection

- In order to welcome the latest international directives related to environmental issues, entrepreneurs/owners are getting used to request more sustainable development of their assets. It concerns with reducing the harmful emissions during all life cycle, paying attention to respect all the standardized practises which strive to contain the whole impact and facilitate a appropriate integration between humans been and environment.

4.4 Design team

Safety and security

- For the design team the demand of safety and security deals with the necessity to assure the work safety for all the members and in every stage of the project development, especially during the on-site manufacturing. This is strongly felt due to the construction sector in China numbers a high number of death tools and injured workers (around 36% of the whole accidents across industrial sector occurring in one year are recorded in construction field, Accident Map reported (China Labour Bulletin, 2018). If in the last few years there has been a steady decline of fatal accidents, the indicators for the 2018 display an average of 134 accidents each day. According to the rates, the 31% of the total accidents are seen in the construction and engineering sectors due to mechanical and structural failures. Since 1994, Chinese government enacted some strong laws to protect workers from dangerous working conditions, establishing a fix salary that the employers must guarantee as a contract. Moreover, it was established the maximum number of working hours at 44 per week, followed by new innovative measures regarding the whole working aspects, from the safety of the working places to the woman rights (Tomasi, 2012).

Wellness

- The first wellness demand deals with the necessity of integration and cooperation among the various professionals who take part in the design team. In order to work in a constructive environment, it is important to assign precise tasks to every expert who has the commitment of respecting the scheduled deadlines and establishing a dialogue with his/her colleagues.
- Working in an appropriate place with defined schedule timetable is the main demand asked by design team. Moreover, the work should by carried out without any economic blackmails and pressures. It depends on the type of the company in which the design team is involved. In fact, the company typology are described according to due acronyms: “POE” which stands for Private Owned Enterprise, whereas “SOE” which sands for State-Owned Enterprise.

Usability

- In terms of usability, design team calls for the availability of all information in relation to the design aspects to reach a high-quality final project proposal. It means that they should be able to find the materials about the extent of the work, the site, the design tools, the duration and the budgeted cost of work scheduled.

Appearance

- The demand of appearance is important for those design teams which have to emerge within a tender in which other competitors are involved. Especially in international challenges, the presentation of the panels with advanced graphic contents plays a fundamental role in the choice of the successful design solution, carried out by the evaluation committee. The quality of team members is also an element that increases the company's appeal.

Management

- The management demand is crucial for the design team because designers must meet restrict schedule, limited budget and ensure the quality of the final product in accordance with the performance requirements defined previously. Thus, some members of the design team are themselves in charge of the economic, the human resources, the construction site, the maintenance and the end-of-life management. For this reason, the design team should count project managers because they are the professionals able to balance the different needs in terms of time, cost ad quality.

4.5 Manufacturer

Safety and security

- As already mentioned related to design team, safe and secure work is broadly demanded by manufacturers given that the statistics show as the construction sector in China owns

an high number of death tools and injured workers. Many accidents are triggered by the break of the structural elements employed during the construction process. This is the consequence of shortage of safety equipment and behaviours. Moreover, if unfortunately some cases of injury or death occur, it is be difficult for workers to demonstrate that the cause is related to their employment.

- Manufacturers would want better transparency on workplace safety in order to make politicians and civil society more aware that the prevention against risks is essential and to encourage the formulation of new measures. Many institutions, such as China Labour Bulletin, have already issued their recommendations to improve the safety and security in all workplaces. Substantially, they deal with the need of create some committees or trade unions that should spread out the safety knowledge and manners among workers, inform workers on the potentials dangers they can incur into and bring to the attention of the authorities the behaviour that can affect workers safety.

Wellness

- The demand of wellness is embodied by the necessity to live in a health environment during the working schedule. Manufacturer want to avoid being exposed to toxic emissions and contaminations during the production processes, either in the warehouse or in the construction site. Wellness is intended for physical and psychological point of view: this means that manufacturers not only ask for comfortable ambiences to work in but also for the respect of the payment due by contractors after that they completed their task, for the rights in terms of salary and working time and for the respect of the independence of any external influences.

Usability

- As the design team, manufacturers request that design information are clearly specified in order to reach a high-quality final project proposal. Here also the meaning is that they should be able to find the materials about the extent of the work, the site, the design tools, the duration and the budgeted cost of work scheduled.

Appearance

- In term of appearance, manufactures request to possess the means to reach a good-looking final product. His means that they could use advanced machineries to yield their stocks, have the knowledge to manage the production processes and use materials and techniques that assure to be competitive in terms of quality and benefits.

Compatibility

- At this point, it is relevant to add the demand of integrability and compatibility for the manufacturers. In fact, those require that during the construction phases there is coherence between what was approved in the executive project by the design team and what actually realized. This is significant to avoid incurring into variations in progress that create inconveniences both from a time and cost point of view.

Management

- Manufacturers strive for the most efficient management of all the activities they carry out. It should be guaranteed the balance among several aspects on which manufacturers root their production. First of all, it should be known the workforce available for the construction/ production phases; then the economic resources which have to be invest in all stages of manufacture; the time necessary to conclude the work and, finally, the quality to which it is expected to tend.

4.6 Public administration

Safety and security

- Public administration requires continuous work to update and improve current safety laws in every sector. National and local governments solicit that their functionaries can apply the law guaranteeing valid contracts and insurances related to injuries provoked by work. This demand is valid for all workers «so that in the event of injury, workers can prove they have

an employment relationship and pursue claims for work-related injury compensation more easily» (China Labour Bulletin, 2018).

- Moreover, public administration wants to disclosure to the media and the public figures about the accidents which occurred on workplace in order to inform and sensitise the workers. It requests that workers organize themselves to participate, supervise and manage safety during all stages of production, in order to legitimize and safeguard their rights and concerns.
- Public administration stimulates employers to improve the safety system which must comply with the standards of national directives. Employees must be always informed by their employers about the current rules and the correct use of machinery and working equipment. If the employer decides or orders his employees to break these rules, workers have the right to refuse to perform their duties and informed the competent authority to take the measures.

Wellness

- In order to meet the need of wellness, public administration seeks to be independent from strong private powers such as big national and foreign companies which try to put pressure to gain some favoritism. Moreover, it is strongly requested more transparency in the various relationships with internal apparats and external one.

Appearance

- Public institutions request to represent themselves as example for the people. It means that they should apply the best practises both from practical and behaviour point of view. Practical aspects deal with the design of public offices which are completely accessible and devoid of architectural barriers and other form of obstacles. Behaviour points concern the fact that public administrations and institutions want to flank the citizens to make them safer, more relaxed and conscious.

Management

- It is the political elites, based on their perception of reality and their preferences, who set the decision-making agenda and define the action to take. The trend of foreign policy is influenced by the internal dynamics of the small group of people who control the state apparatus: level of organization, cohesion, motivations, degree of conflict, propensity to train coalitions.

4.7 Stakeholders' needs comparisons and final considerations

Once having taken into account the different stakeholders' needs, it is interesting to briefly compere them and see how the same need can assume different faces according to the stakeholder considered. Moreover, having a global overview, it is possible to understand what need is felt the most: this can be useful for the professionals involved in the Chinese construction field. Starting with safety and security, in the current Chinese context, this need is primarily associated with the protection against environmental and anthropic disasters such as earthquakes, fire, pollution and contamination of harmful substances. In addition, some other stakeholders' classes such as design teams and manufacturers consider this need more related to the risk prevention against the production phases and the on-site manufacturing, asking for the application of work safety laws in every stage of the project development. The need of wellness shows the divergence between how it is claimed by users and entrepreneurs/owners and the rest of the classes analysed; indeed, the first two groups of stakeholders ask an improvement related to the indoor environmental comfort which includes thermal and acoustic aspects along with water and air quality. These enhancements can make the constructions more competitive on the market heighten the potential incomes. For the other classes, wellness is more related to the quality of working conditions and the relationships created among the different parts involved in the project. Usability results to be very important for contemporary users who strive for more accessible and bigger spaces where architectural barriers are eliminated. Due to the fact this need has been often undermined in the past, this need is the demonstration of the current intention in China of changing the bad practises employed in the past towards better spatial standards.

STAKEHOLDERS

STAKEHOLDERS' NEEDS	Users	Entrepreneur/owner
Safety and security	• solid buildings earthquake-proof • houses will be available after the earthquake • safety against fire • protection against natural and anthropic disasters • security in terms of housebreaking • safety against the risk of harmful substances contamination	• safe against every environmental threat such as earthquakes, fires, harmful substances contaminations, floods, landslides • risk-free ambience in relation to economic and operating aspects
Wellness	• improve the indoor environmental comfort (thermal and acoustic) • improve indoor and outdoor air quality • improve drinkable water quality	• acoustic and thermal appropriate comfort, indoor and outdoor air quality and the environmental pollution • they look for more efficient technologies to be more competitive in the construction marketplace
Usability	• general better housing standards • enhancement of square meters • eliminate the architectural barriers which characterize indoor and outdoor spaces	• spaces accessible for people of all age groups without distinctions • Western standards in term of design of space without architectonical barriers • room where people can move inside safely and healthy
Appearance	• luxury orientation • transformation of indoor spaces according to their practical needs or just to enjoy it	• increasingly innovative and classy solutions • use of fine finishes, employing high quality materials such as stone or ceramic
Compatibility		
Management	• efficient and durable buildings to reduce extraordinary maintenance • management entrusts to private professionals or administration companies	• rational and well-organized management of all life cycle project's phases • Entrepreneurs/owners do not want to be involved in bribery logic which could compromise their investments
Environmental protection		• request more sustainable development of their assets. • reducing the harmful emissions during all life cycle, paying attention to respect all the standardized practises

STAKEHOLDERS

STAKEHOLDERS' NEEDS	Design team	Manufacturer	Public administration
	• assure the work safety for all the members and in every stage of the project development, especially during the on-site manufacturing	• better transparency on workplace safety in order to make politicians and civil society more aware that the prevention against risks is essential • assure the work safety for all the members and in every stage of the project development	• continuous work to update and improve current safety laws in every sector • disclosure to the media about the accidents which occurred on workplace in order to inform and sensitise the workers • refine the safety and hygiene system which must comply with the standards of national directives
	• integration and cooperation among the various professionals who take part in the design team • Working in an appropriate place with defined schedule timetable	• necessity to live in a health environment during the working schedule	• be independent from strong private powers such as big national and foreign companies which try to put pressure to gain some favoritism
	• availability of all information in relation to the design aspects to reach a high-quality final project proposal	• design information must be clearly specified in order to reach a high-quality final project proposal	
	• appearance is important for those design teams which have to emerge within a tender in which other competitors are involved	• possess the means to reach a good-looking final product such as advanced machineries and have the knowledge to manage the production processes	• request to represent themselves as example for the people • they should apply the best practises both from practical and behaviour point of view
		• during the construction phases there is coherence between what was approved in the executive project by the design team and what actually realized	
	• designers must meet restrict schedule, limited budget and ensure the quality of the final product in accordance with the performance requirements defined previously	• the most efficient management of all the activities they carry out	• policies follows a top down trend

At the same time, it is interesting to notice as this new need comes together with the necessity of luxury and high-quality material in construction. Public administration, though, does not asks for concrete appearance but for institutional appearance which means to present itself as a model of transparent behaviour applicable by every citizen. By the analysis of the management need, it emerges that it is strongly requested the specific profession of a manager who can handle the complex task which are included in the project process. An appropriate professional is also requested after the completion of the construction phase in order to avoid unnecessary cost, for instance extraordinary maintenance. Another controversial need deals with the environmental protection. Although it is a big issue, from this analysis it appears that environmental problems are still not principal for the majority of the stakeholders' classes revelling that it must be bring more attention on this topic in the contemporary China.

5. PRECAST CONCRETE PANELS PERFORMANCE REQUIREMENTS

5.1 The performance requirements analysed

The requirements analysed have been selected as the most suitable to translate the list of stakeholders' needs collected in the previous chapter and to meet the most advanced standards in the design of precast concrete panels. They encompass thermal parameters, acoustic performance, moisture safety, IAQ (indoor air quality), composition, appearance, energy production from renewable sources, communication and durability. The approach followed targets to select the key content of each requirement to obtain the most clear and accessible result. Especially regarding thermal and acoustic requirements, only the fundamental formulas have been reported, avoiding long and complicated mathematic demonstration. Considering their complexity, the thermal parameters are treated in two different part where the first one deals with the most efficient thermal strategies whereas the second one reports the principal parameters that describe the phenomenon. Acoustic performances and moisture safety report both an analytical and mathematical component, as well. The section related to the appearance has been divided into two parts to allow the primary comprehension the main portions which constitute a precast concrete panels façade and the array of finishes that are available for this technology. The requirement of energy production as been treated considering the most popular applications available on the international market which allow to obtain green energy. Related to this, it has been reported the requirement of communication: it deals with the different way to display the building rates, such as the amount of energy produced or consumed during a certain period. The last requirement is more related to the engineering aspect, precisely related to the concrete best practises in order to obtain a resist and durable final product.

5.2 Thermal strategies and parameters

Orientation

Once taken into account the main parameters which define the thermal performance requirement, it is time to go through same design practises which are central to restrain energy consumption. The first aspect deals with the building orientation. There is not a simple solution applicable for every case but it depends on at least three factors:

- the final use of the building
- the activities performed
- the climatic zone

In the case of residential building it should be privileged the east-west orientation. The reason is related to the better sun control which implies the reduction of heat and cool gains. In the case of office buildings, the orientation north-south may be preferred: these buildings are occupied throughout the day whereas are empty during the night hence it needs use as much as possible the daylight in order to reduce the energy consumption due to lamps lighted. The designers can opt for wide glazing surfaces located on the south to increase the heat gains thanks to the winter sunshine. In order to avoid excessive heat gains in the summer, south-facing glasses are preferred in combination with some shading devices whereas north-facing façade must employ insulating glasses such as double or triple pane windows.

Building shape

The building shape is directly connected to the dimension of the surface area of the building. There is a direct proportionality between the cladding area and the heat gain and dissipation: It is proved that an ampler cladding area correspond to a more considerable heat or loss gain, respectively in summer or winter time. Another point is that the shape allows to estimate the amount of daylight which can illuminate the floor area.

Glazing

The clear portion of windows is the weakest part of the cladding in terms of thermal efficient both for heating and cooling maters. The requirements about glazing are strongly influenced by several aspects that encompass the number, the typology, the orientation, heating and cooling factors, daylighting and mental comfort. To find a suitable solution which accommodates all the requirements, it is fundamental to adopt high-performance glazing. They perform several advanced properties such as low emissivity (low-E), useful in cold climate to avoid high heat dispersions, multilayers glass which reduce U-value or selective glasses which shade the direct infrared radiation. In absence of any shading devices, the direct solar gains can also cause annoying glare on the surfaces. To fulfil the thermal insulation requirement, glazing should be characterised by low solar heat gain and be pervious to light transmittance.

Daylight

Taking into consideration the entire energy balance, lighting can affect remarkably the final value. For this reason, daylighting should be enough according to the use of the building, in order to replace the artificial light illumination with natural one. Commercial buildings are recorded to consume large electrical energy because of their activities; thus the glazing should be pervious to natural light to save energy from daylight. Good practises to improve daylighting is working on the size and location of the window combined olso with suitable shading devices.

Colour

The colour of the precast concrete panels plays a fundamental role in terms of energy conservation. The physical parameter associated to the colour is called albedo and it represents the ratio between the ability of a surface to reflect solar radiation and the quantity that sparkles on the surface (PCI,2007). The lighter is the colour, the higher is the albedo and its values are encompassed from 0 to 1. The 0 value corresponds to the maximum absorption of the sun irradiation, whereas the 1 value indicates that all the energy which hits the surface is entirely reflected. This means that concrete superficial coating shall be characterised by high albedo employing

consequently light colours; the purpose is to control and decrease solar heat gain, especially for heavily exposed surfaces. High albedo should be guaranteed also in order to lessen the urban heat island effect. Indeed, due to the large extension of artificial surfaces such as buildings and pavements which have replaced vegetation, urban areas can be account up to 4 °C warmer than the surrounding areas.

Shading

Shading systems are essential to control the direct sun radiation throughout the year. They are added to the cladding to prevent peaks of heat gain and to avoid phenomena of glare inside or upon the façade of the building. Precast concrete panels have a large possibility of shape and installation of shading devices which are designed from time to time to guarantee the thermal and visual comfort. They may enrich the aesthetic of the building thank to the vast variety of configurations, materials and locations that they can assume. Thanks to the workability of the fresh concrete, it is possible to define numerous sculptured shading devices which can be vertically or horizontally oriented, including also detached screen panels which run parallelly across the façade. It allows also windows to be recessed, surrounded by a concrete enclosing envelope with an overhang of some centimeters up to a couple of metres. In wintertime, when the orientation of the sun creates a low angle of incidence, the shading systems should be tilted by a certain angle in order to permit the sunshine to come in and to contribute to reduce heating loads on the building's heating system. Tilted devices may have shorter length, but they may potentially create an obstacle which reduces the view of the sky. Moreover, the use of vertical fins does not obstruct the penetration of the daylight given that the low altitude of the sun in the cooler season. In summer, vertical fins are useful to shade sun's irradiation in two parts of the day: at the early morning and at late afternoon. Vertical fins are recommended to shade east and west facing windows. On the other hand, horizontal fins shade the mid-day high-altitude irradiation and they are more effective if are positioned on southern exposures designed with the right overhang beyond the façade.

Thermal insulation

Thermal insulation is one of the principal requirements that precast concrete cladding must to meet to assure an appropriate indoor comfort and to reduce the heat dispersions through the buildin envelope. Panel must have a proper sequence of layers, each of these characterized by coherent value of thermal conductivity and water steam resistance factor, in order to verify the absence of superficial and interstitial condensation. Moreover, joints and connections between elements must to be performant and efficient in order to avoid thermal bridges. The surfaces must guarantee homogeneous superficial temperature, in particular the internal lining must not have cold parts of surface also including glazing components.

To rate the various thermal performance requirements, different parameters have been introduced. It is always important to analyse the wall panels as a component made by different layers flanked each other. Each layer has its own physical characteristics which contribute to determine the comprehensive panel's performances. The main aspects which influence the energy performance of building's precast concrete panel are their mass, cladding colour, air infiltration, shading or reflections from the surrounding elements, glass area, building orientation, wind speed, building shape and height.

Thanks to the measure of the heat which passes from the warm side to the cool side of sample panel, it is possible to define the thermal properties of materials and air spaces. These tests are assessed in a steady state which means that the wall system is in a dynamic equilibrium so «there is no accumulation of mass or energy within the control volume, and the properties at any point within the system are independent of time». (Engineers Edge, n.d.)

This approach allows to calculate three fundamental parameters which are the thermal conductivity, the thermal resistance (R-value) and the thermal transmittance (U value). It must be clarify two important premises:

- The thermal conductivity of each layer constituting the panel directly influences its thermal resistance.

- Each layer is considered as homogenous, so it means that it has the same properties in all points and directions of the system.

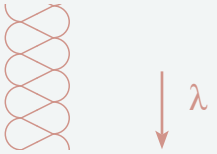
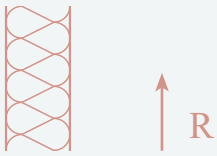
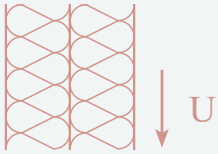
THERMAL CONDUCTIVITY	**λ [W/mK]**	Reducing λ, it increases the material's insulating capacity	
THERMAL RESISTANCE	**R [m²K/W]**	Increasing R, it increases the material's insulating capacity	
THERMAL TRANSMITTANCE	**U [W/m²K]**	Reducing U, it increases the material's insulating capacity	

Fig. 5.1 The main thermal parameters affecting thermal insulation

Thermal conductivity

The first parameter treated is thermal conductivity (λ) [W/(m•K)]. It represents the transport of energy, specifically heat, which pass through a body as a result of a temperature gradient. The heat always flows in the direction from the higher temperature to the lower one, according to the second principle of thermodynamics. Hence, the equation for thermal conductivity represents the relationship between the heat transferred per unit of time (Q) and the temperature gradient through an area A. The heat passes through this area perpendicularly and with a constant speed. The ultimate definition could be: «the conductivity of a material is the rate at which heat is transmitted, measured in Watts per square metre of surface area for a temperature gradient of one Kelvin per metre thickness» (Baird, 2014, p. 16). Thermal conductivity is therefore an enherent property of the material.

Thermal resistance

The second parameter obtain as a result of steady-state tests is the thermal resistance (R-value). Each layer such as air gap, material, or combination of materials owns its R-value. This value is commonly used to quantify the thermal performance. Thermal resistance is defined as the ratio between the thickness of the material (expressed in m) and the conductivity of that material itself (Baird, 2014, p. 16). The R-value of a homogenous material is equal to the inverse of its thermal conductivity. Despite the fact that daily temperature swings and hence thermal resistance varies depending on the temperature, it is commonly accepted in the construction applications to treat it as a constant value. It is important to assure the higher R-value, in order to obtain a high thermal performance panel.

The total R-value of a building wall is computed by considering the different contributes given by the different wall layers. For this reason, there will be the R-value referred to the materials located inside to wall, called $R_{materials}$, the indoor and outdoor air film surfaces, called R_{fi} and R_{fo}, and air spaces within the section, called R_a (PCI, 2007, p. 404). The applications are only possible if each layer is composed of a homogenous material. This can be summarised as it follows:

$$R_{total} = R_{fi}+R_{materials}+R_a+R_{fo}$$

Thermal transmittance

Thermal transmittance is the parameter which assesses heat dissipation through a wall. It represents the heat flow which passes through the unit area of a cladding surface, due to the difference of 1 ^{o}C between the internal and external temperature. It is the inverse of the total R-value ($U = 1/R_{total}$). The standard for calculating thermal transmittance and thermal resistance is the UNI EN ISO 6946:2008. The U-Value is an effective parameter for evaluate thermal properties because it is able to take into account the thermal resistance of each wall layer, air gaps, thermal bridges and fixings. The lower is the U-value of a building's cladding, the lower will be the heat flow which passes through the external walls, and so the envelope will be more efficient from thermal point of view. The same concept is also applied for glazing cladding's components such

as windows. The calculation of thermal transmittance for solid elements can be done using the following formula:

$$U = \frac{1}{\frac{1}{h_i} + \sum_{j=1}^{n} \frac{s_j}{\lambda_j} + \sum_{j=1}^{m} R_k + \frac{1}{h_e}} \qquad \left[\frac{W}{m^2K}\right]$$

n = the number of the homogeneous layers
s = the thickness of each layer
λ = thermal conductivity
m = the number of the non-homogeneous layers (such as air gaps)
R_k = thermal resistance of non-homogeneous layers
h_i = internal heat transfer coefficient
h_e = external heat transfer coefficient

There is also a specific formula which allows to calculate thermal transmittance of glazing elements. The variables that affect the calculation are the glass typology, the frame typology, the use of the building and its cladding system. The thermal trasmittance of windows (Uw) is calculated according to the international code UNI EN ISO 10077-1: 2007.

$$U_w = \frac{A_g \cdot U_g + A_f \cdot U_f + I_g \cdot \Psi_g}{A_g + A_f} \qquad \left[\frac{W}{m^2K}\right]$$

A_g = the glass area
U_g = the glass thermal transmittance
A_f = the frame area
U_f = the frame thermal transmittance
I_g = the length of window spacer
Ψ_g = the linear thermal transmittance for the glass

Thermal bridges

A thermal bridge occurs when an area of the building cladding has a thermal resistance that tends to near zero. There are two typologies: linear thermal bridges and point thermal bridges. The examples of the first typology occur in presence of joints between wall and balcony slabs, joints between wall and window frames, external wall corners, junction between concrete pillar and wall, junction between wall and floor. These phenomena are triggered by the inherent geometry of the cladding. The most critical points are the cladding edges and the joints between two panels where there is a concentration of the dispersive thermal flow. The examples of point thermal bridges are seen due to metal connectors, bolts fixings and pillars attached to the slab.
Another general cause of thermal bridges is due to the matching of materials characterised by a poor insulation value. In the case of precast concrete panels, the problem is caused to excessive air exfiltration located where there are some cracks, deteriorated parts and precast concrete connectors. Connectors are particularly critical because they are made of steel which is characterised by high thermal conductivity. This creates suitable environment for condensation.
To guarantee high insulation performances and cladding's durability, it is crucial to eliminate permanently the possible thermal bridges by designing the section of the panel with better insulating materials (Baird, 2014, p. 17). In order to exemplify some of the best practises employed to reduce thermal bridges, it must be mentioned the use of low conductivity materials, appropriate sealants, insulated concrete panel and the adoption of construction techniques which allow to maintain the cross-section layers homogeneous.
Parameters that describe the influence of the thermal bridge on the total heat flow are: linear thermal transmittance ψ (W/m K) and point thermal transmittance X (W/K).

Thermal mass

Although they are the easiest and most employed parameters concerning thermal properties, thermal resistance and thermal transmittance describe only partially the thermal behaviour of cladding systems since they are based on steady-state conditions.
Nevertheless, these conditions appear rarely and invalidate the description of the real condi-

tions which naturally swing throughout the day: for example the external temperature and the sun position change continuously and consequently heat gain is not instantaneous but it has a time lag (PCI, 2007, p. 412). Thanks to thermal mass, it is possible to delay peak of heat loads to a later time, reducing the building's energy supply.

Finally, thermal mass consists of the ability of a material to obstruct the passage of heat flow and to accumulate a part of it, while maintaining a homogeneous, constant and comfortable internal ambient temperature, despite variable external temperatures. It means that the material can accumulate heat preventing that the sudden changes of external temperature would be able to be directly reflected inside the building. This delay with which the wall cladding releases the accumulated heat is called a lag, and indicates the time employed by the heat flow absorbed by one side of the cladding to pass through it and to be released to the external environment.

Regarding the concrete, it shows considerable absorption and storage of large quantities of heat thanks to its density. The higher is its density the higher will be its thermal mass: an higher thermal mass allows concrete to reduce the consequences of the outside temperature fluctuations. Thus, it shrinks heating and cooling peaks and delays the time at which these peak loads occur. Having taken these points into consideration it is important to underline that lightweight materials are not efficient to contrast peak loads and so to save energy. The thermal mass provided by precast concrete panels saves energy and guarantee good insulating properties.

5.3 Acoustic performance

After having taken into account the users need, it has emerged that one of the most felt issue is the necessity of acoustic comfort. As already well-know, precast concrete cladding has to play an important role to avoid that the noise can come into the building, disturbing its occupants. This is more relevant in the context of Chinese cities which are generally affected by large avenues with permanent heavy traffic noise. Given that the road infrastructures represent a massive network presence into the cities, the sound level recorded inside the nearest buildings often exceeds the limits imposed. For this reason, the correct cladding design is mandatory to provide environments in which the sound may be clearly heard, and noise may be isolated and adsorbed. Thus, designers must be attentive to create the correct sequence of panel's layers and appropri-

ate mass to muffle disturbing sound coming from outside. Reflective, absorptive surfaces and sound barriers are the most employed devices to cope with the acoustic issue.

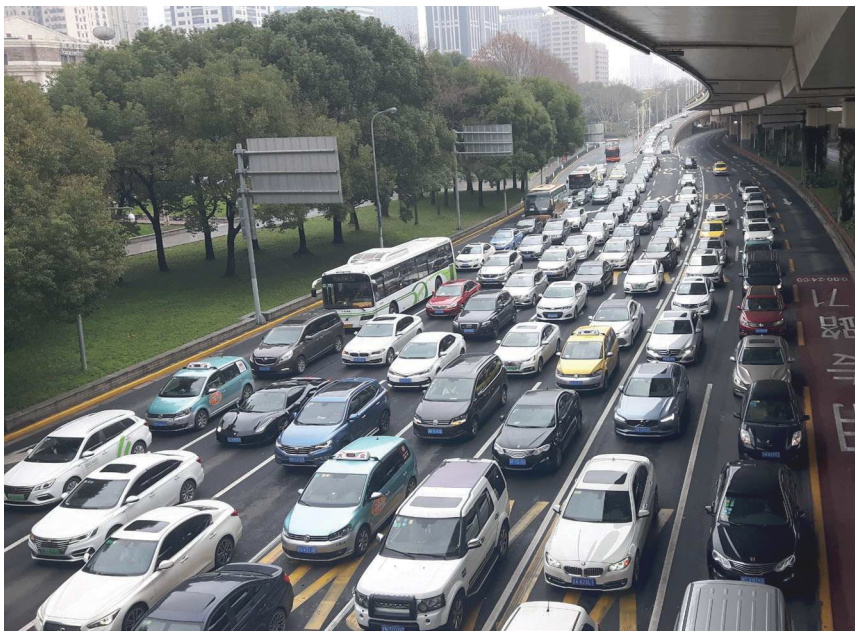


Fig. 5.2 The heavy traffic affecting Shanghai main streets
Yan'an E Road (Shanghai,2019)

Noise reduction

To assure noise reduction it is fundamental that the insulating barrier is impervious and splayed continuously. This aspect is particularly challenging applied to precast concrete panels given that the technology itself needs that separated units must be arranged together. Hence, exactly as it happens for thermal insulation, joints and connections are the weakest points of the cladding and along their length are concentrated the most severe acoustic bridges and loss of insulation. For this reason, as regard the acoustic insulation of a precast concrete panel, it will be only considered as disturbing source the airborne sound, excluding flanking transmission between rooms.

Airborne sound is responsible for the vibrations which affect walls, floors and ceilings. In their turn, vibrations transport the sound energy with a reduced intensity to the adjacent room causing noise. The characteristics of stiffness, vibration damping and weight are essential to guarantee airborne sound transmission loss. Thanks to its mass and density, concrete displays high performances as a sound insulator. Generally, the inherence characteristics of precast concrete walls are sufficient to assure sound transmission loss without employing other devices. How-

ever, considering different cases studies with different requirements, the sole concrete barrier can be improved with other materials such as single or double layers of gypsum board or an air gap layer.

In order to avoid the discussion over complex acoustic parameters, it follows the international standard for the calculation of the acoustic insulation of a generic cladding system called UNI EN ISO 140-5/2000. The sound insulation of the façade D_{2m} is the difference between the average value of the level of sound pressure at 2 meters from the cladding ($L_{1,2m}$) and the average value of the level of sound pressure in the receiving room (L_2).

$$D_{2m} = L_{1,2m} - L_2 \text{ (dB)}$$

The calculation requests the assessment of the acoustic insulation index standardised as $D_{2m,nT,w}$. It is formulated considering as the benchmark the traffic noise or a sound source with an emission at 45° to the façade.

$$D_{2m,nT,w} = D_{2m} + 10 \log \frac{T}{T_0} \quad \text{dB}$$

T stands by reverberation time of the receiving room[s] whereas T0 stands by the benchmark reverberation time equal to 0,5 s.

Weakest points

Considering the cladding system, the first elements which significantly contribute to the entering of external noise are the windows. In order to enhance the sound transmission loss, it is necessary to choose a suitable window panes and frames. First of all, it is important to use double glasses with a thickness of the air gap which must be the amplest possible. The glasses must be installed upon detached frames and hold by dumping sealant. Moreover, the panes must have different thickness. As concern the frames, the characteristics of sound insulation are determined by their airtight: for this reason, it must guarantee the highest airtight. The frame's material does not considerably influenced the performance of sound insulation.

Sound absorption

The sound absorption is defined as the reductions of sound level into a sample room using a suitable absorbing material. This phenomenon is based upon the fact that a sound wave loses a portion of its energy when it is reflected by a surface. The decrease of the sound pressure and consequently wave energy due to the multiple reflections is another way to describe the sound absorption. It results clear that to avoid reverberation into the room it is important to be focused on the sound absorption coefficient. The assessment of sound absorption can be made considering the NRC value. NRC stands for Noise Reduction Coefficient and it is an average of absorption coefficients which rates how well a material absorbs sound. NRC of a material is expressed as a percentage. In the case of concrete, if it has a good density and thus low porosity, its surface is characterised by a NRC of 0.015 which correspond to an absorption of 1 to 2% of incident sound. In specific applications, such as auditorium or screening room, it can be requested an additional sound absorption which can be reached thanks to the use of a coating of acoustic material. Involving higher costs, there is the application of acoustical tiles sticked on concrete surface or, in the case of ceiling, the installation is based on tiles in suspension.

5.4 Moisture safety

Adding to heat transfer, building's cladding is also affected by water vapour diffusion. It is triggered by the difference of pressure existing in the internal and external environments. The condensation happens when the steam pressure reaches the saturation stage and it means that steam is transformed in liquid state. This event generally take place in the building cladding during wintertime. There are two types of condensation: interstitial when it occurs on the inner surface of the wall and surficial when it occurs inside the wall.

Superficial condensation

The superficial condensation is triggered when surficial temperature equals the dew temperature of the air and it depends on the fact that the steam pressure at the inner surface of the wall is

equal to the steam pressure of the environment air. It is necessary to check that the temperature of the inner surface of the wall is higher than the dew temperature of the internal air. Thanks to this approach it is possible to prevent the wall from superficial condensation

$t_{i,s} > t_{i,d}$

$t_{i,s}$ = temperature of the inner surface
$t_{i,d}$ = dew temperature of the internal air

Interstitial condensation

In order to avoid the interstitial condensation, it is necessary that at all points in the wall the steam pressure is kept below the saturation pressure, which is expressed by:

$p_1 < p_2$

p_1 = steam pressure
p_2 = saturation pressure

The interstitial condensation check is carried out following some steps: first of all, it must define the temperature profile in the wall and consequently it is necessary the identification of the saturation pressure profile. The saturation pressure is directly proportional to the temperature profile. After that, it follows the determination of the steam pressure profile inside the wall and the comparison between the profiles of steam pressure and saturation pressure. In the end, if it is necessary, there is the calculation of the possible condensed steam flow rate inside the wall. The easiest way to represent all these aspects can be applied by using the Glaser diagram. It is the schematic illustration of the different layers of a wall, employing the Cartesian convention. Abscissa and ordinate report respectively the steam diffusion and the steam pressure values in the different wall layers.

5.5 IAQ Indoor Air Quality

Dealing with indoor air quality, it is strictly fundamental that the precast concrete panels are completely free from harmful substances which can be emitted inside the building ambiences. Indoor pollution refers to the presence of physical, chemical and biological contaminants in the indoor air. The indoor air refers to living and working buildings including also means of transport. Some examples of these categories are hospitals, schools, offices, hotels, banks, cinemas, bars, restaurants, shops, sport facilities, cars, trains, planes, ships, etc.

Building materials play a very important role in determining the IAQ for two reasons: the width of their area exposed to the indoor air and the illimited duration of their exposition. The construction materials can emit pollutants, such as VOCs, which can have impacts on the human health. In particular, the key material which could generate potential toxic emissions is concrete because is the core material of the precast concrete panels and it is directly in contact with the internal air. As it is already treated in the users' needs, the problem of indoor air quality is one of the main concerns for the majority of Cinese citizens because the presence of toxic pollutants in the air can lead to serious health problems, such as respiratory problems related to asthma or lungs cancer. Considering that Cinenese citizens spend most of their time indoor, legislators have prioritised the assessment of the different ways in which indoor air quality can be improved. Many factors can help to reduce the indoor air quality: tobacco smoke, high levels of VOCs, odors derived from products used for cleaning, personal care, and burning oils, gas, kerosene, coal, wood, etc. Even if the causes are well-knewn, there is still a shortage of codes which can univocally provide the thresholds value of the different pollutants. The World Health Organization (WHO) has carried out for European countries the Guidelines for the IAQ. It has the purpose to identify the pollutants which can strongly affect the human health according to specific scientific experiments. The substances identified are: aromatic polycyclic hydrocarbons, benzene, naphthalene, trichloroethylene, carbon monoxide, radon, nitrogen and dioxide (WHO, 2010).

Currently the Italian and Chinese legislation has not already defined a unique guideline about the threshold value of pollutants emissions. However, the criteria or standards adopted in other countries can be considered as an orientation of the values. For instance, this applies for the

finish materials such as paints which cause large emissions of VOCs. For these products, in the European context, it has been taken the French and German threshold values as the benchmark for the other communitarian countries. Additionally, according to the Italian codes, the indoor air quality can be classified from IDA 4 (low IAQ) to IDA 1 (high IAQ). The four parameters depend on the concentration of CO_2 (ppm) in the indoor air compared with the external air. IDA 4 corresponds to a concentration higher than 1000 ppm whereas the IDA 1 correspond to a concentration lower than 400 ppm.

Coming up to the potencial pollution crated by the concrete, it contains minimum levels of VOCs, which are able to degrade indoor air quality. These volatile organic compounds are generally released as gases from the new building materials. Thanks to the fact that concrete is an inert material, it does not require additional finishing products, ensuring healthier and more hygienic indoor air quality. During its realisation, it is possible to lessen the volatile organic compounds emissions by adopting low VOCs sealants, repellent and insulating materials.

5.6 Weathertight

Precast concrete panels should be designed to guarantee a sufficient level of weathertight. Weathertight concept can be cleared as the combination of two crucial requirements: from one side it represents the capability of the cladding system to be airtight and at the same time to resist against the penetration of the water that means watertight. At the first glance, the airtight and watertight requirements could be considered as the same nature but they are important for different reasons.

Starting with airtight, it plays a crucial role to define the energy efficiency rate of the cladding system. Indeed, if the panel is subjected to an important infiltration and/or exfiltration of the air, especially through its joints, it means that its capacity of preserve the cool and heat is low. For this reason, the airtight requirement has a consequential impact upon the rate of heat loss which is translated in terms of physical parameters as the thermal transmittance or U-value. However, it is rather complicated to exactly determine the negative contribute which a low airtight capacity has in terms of thermal transmittance. It is possible to verify this phenomenon thanks to a specific test called air infiltration test, even though it is difficult to be assesses the exact amount

of heat and cool dissipation with high accuracy.

As it has been already mentioned, there is a direct link between airtight and watertight requirements of a cladding system which means that large air infiltration will often implies a high permeable cladding. As it happens to assess the airtight performances of a cladding, there is a specific test which produce the rate of cladding watertight. The weakest points where the air and water leakage are most accentuated are the joints. The design of the panel joints must encompasses a suitable profile to allow water to be drained towars the external part of the cladding.

5.7 Composition

Due to the nearly infinite possibilities of finishing and arrangements of precast concrete panels, the discussion about surface aesthetic is oriented firstly in understanding how a façade composition should be designed by architects.

The first consideration about aesthetic is related to the moulds configuration which are in charge of defining the final aspect of the precast concrete panels. The material used and the number of moulds depend on a project schedule. The power of repetition is the key concept which allows to achieve cladding variety, appearance appeal and economy. To display these aspects, the façade of a precast building can be breakdown in three parts: at the lowest level there is the ground floor where the design of the façade must capture the users glance and clearly define its aspect. It is important, especially in the big cities, to attract people thanks to the external image of the building which can create a sort of iconic appearance. Hence, in this bay it is concentrated the most relevant architectural expression and elaborated details. Moving upward, there is the typical floors which are generally characterised by the replication of a panel modulus, in order to define the façade pattern required. In terms of width, this part occupies the ampler part of the external envelop, defining the aspect of the building which can be noticed in the urban scale. At the highest level of the façade there is the top part characterised by a solid appearance, sometimes decorated with parapet. In terms of variety, there are generally three possible configurations whom the first one has uniform design from the first floor up whereas the base shows a different pattern. Second possible layout expresses uniformity from the ground up and have a variation at the top. The last arrangement is represented by three separated compositional parts,

ground floor, central body and the top.

The podium

The lowest part of the building, also known as podium, it houses doors and wide openings both for functional needs such as the accessibility and appearance reason such as show the use of the construction, especially if it deals with commercial contexts. In this case, to optimise the entire manufacturing and installation operations, the precast concrete panels have to be cast in the same mould. The common suggestion is to design flat panels in order to reuse the flat mould to cast also the panels employed for the typical floor walls, obviously applying the due changes. The flat shape allows the panels to be also more economical rather than sculptured ones. Depending on the final use of the building and the appearance wanted, lower level panels can be smaller in width and this means that these units are easy to be assembled, delivered and allow to save costs. However, in some cases precast concrete panels for a ground-floor level often allows the choice of more expensive finishes for this area only.

Typical floors

Typical floors made by precast concrete panels are generally characterised by the repetition of a single unit multiple times as long as it spans all the façade. However, there are more advanced and innovative composition solutions which are able to create complex prospects and fulfil the contemporary needs of novity. The simplest pattern created vertically by a façade is represented by uniform language across the façade from left to right side and from bottom to the top. However, as it has already seen, the most significative changes can take place at the ground floor, especially to underline the entrance doors. Instead of the uniform pattern, the precast concrete panels can display different geometrical logic that encompasses one or more floors. This also implies that probably the top floor appears differently from the previous below and it may also span across one or more floors. The same logic can be applied in horizontal direction which means that the panels are arranged to create a left and right wing with a central body, each of them characterised by different features.

Top floor

The top floor is always associate to the crowning element of the façade. Using precast concrete panels, this part of the prospect employs not excessively large units unless the design and the budget warrant the additional crane cost.

5.8 Surface aesthetics

Precast Concrete Panels Finishes

- *Exposed aggregate - chemically retarded and sandblasted or waterwashed*

  To obtain exposed aggregate finish, it is necessary that the concrete is casted inside a mould that has been covered with retarder chemicals. The aim is always to prevent that the concrete surface can stick across the mould surface, ruining the final finishes of the panel. After the removal from the mould, the retarder is wiped thanks to sandblasting. Instead using the sandblast treatment, the surface of the panel can be worked by a high pressure waterwashing. These finishes should be used where aggregate surface can create a good-looking texture with a matte appearance.

- *Smooth - acid etch*

  After that the concrete is casted inside a mould, the panel is removed and cured. Once ready, the panel surface is treated with an acid liquid to reach the sand surface level. The aesthetic purpose is to obtain a surface with a natural stone looking, characterised by a bright colour. This process should by avoid if applied to wide panel.

- *Form liners finish*

  To obtain this finish it is indispensable the use of this liner material. During the casting of the concrete, it allows to draw a specific finish to the panel surface, obtaining a large range

of different finish options. However, to be sure that the texture carried out by the designers corresponds to the final result, it is fundamental that architects and precasters work together.

- *Tooled finishes*

  To achieve tooled finishes, concrete is casted into a textured mould. This technique allows to produce a sculptured effect after some extra mechanical treatments, obtaining a vast array of surface layouts. The drawbacks deal with the considerable costs needed by this surface and the final result is less standardised that other finishing because generally this type of finishes is carried out by artisans.

- *Natural stone veneer finish*

  The purpose of this type of finish is to obtain a natural stone surface, applied to the concrete core. Some pieces of natural stone such as marble and granite are placed over the mould and behind them the concrete is casted. The positive point of this process is that is allows to save time and money, although from sustainable prospective it generates remarkable impacts.

- *Brick face finish panels*

  Brick face finish panels are obtained with a similar technique of natural stone veneer finish. Indeed, a layer of bricks is arranged over the mould surface and over them it is casted the concrete. Compared with a traditional masonry, these panels request higher costs and work. However, the advantages are a more efficient watertight of cladding and a quicker assembly operation.

5.9 Energy production

Photovoltaic energy

A photovoltaic system (PV) is rooted on the idea that the sunlight can be immediately converted into electricity, without using any mechanical components. This mechanism is possible thanks to the photoelectric effect which uses some semiconductor materials, such as the silicon, to transform the solar radiation into electric power. The basic element of the system is the photovoltaic cell. In standard conditions, with a temperature of 25 °C and a radiation power of 1000 W/m^2, a single cell can produce about 1.5 W of power. The domestic photovoltaic systems are generally connected to the public grid in which they also can enter the self-produced electricity. The two main parameters, used also as benchmarks, referred to a photovoltaic system are the peak power (Wp) and the nominal power. Today, there is a vast range of photovoltaic systems available on the market. The large array of research carried out upon this technology has brought to more efficient, integrable, durable and cheaper systems. Here following are listed the most cutting-edge uses today available:

- *Photovoltaic shadings*

  The photovoltaic shadings are constituted by panels which are attached to the façade in order to capture the solar irradiance and shade the clear surfaces below them. Photovoltaic shadings can also cover an entire glazed facade of a building, assuring the light permeability thanks to the fact that the panels are installed on a transparent support. Hence, considering the cladding on which the photovoltaic cells are going to be realised, it is important to arranged on a matte or a clear background to allow the appropriate penetration of sunlight inside the building.

- *Photovoltaic facade*

  Photovoltaic facades are built in correspondence of building cladding to produce electricity and take advantage of unused spaces. Thanks to their width, photovoltaic walls can have a good gain returns in terms of energy production even they are located in an inconvenient position, affecting their orientation. This application is also able to improve the aesthetic impact and increase the value of the building. The most common uses are on modern manufacture and commercial facilities.

- *Photovoltaic windows*

  Through this application, windows pane can be upgraded with photovoltaic panels installed inside the glasses creating a sandwich stratigraphy. To make the glass safer, a thin film of a plastic resin called PVB is spread across the solar cells and each glass layer. It is able to avoid the dispersion of glass fragments in case of fractures or breaks. This technology represents one of the most advanced way to integrate photovoltaic panels in the conventional components of the building, allowing to produce green energy. The disadvantages are related to the high cost of installation and maintenance and the low amount of energy produced.

- *Photovoltaic parapets*

  The photovoltaic parapets allow to use their surface to produce energy and they can improve the general aesthetic of the façade. They employ the same photovoltaic sandwich panes used for photovoltaic windows. This application allows almost unlimited design possibilities for balconies.

Wind energy

Today, wind energy is becoming more employed in housing context due to the more integrable systems that have been established. The primary requirement to set up this system is the

presence of constant winds ever characterised by low intensity. Putting aside the wide-scale applications, in the domestic environment are always more used the Vertical Axis Wind Turbines (VAWT). They require a big empty space around to be installed but, once in use, they are efficient in taking advantage from any kind of wind blowing. This characteristic makes them employable in every climatic area. They effectively enables to produce up to 1 kW of electrical energy. This technology is still an experiment although it is gaining an increasing consideration among the construction professionals. It means that the cost of installation are high and there is a restrict range of suppliers. The drawbacks concern also about the aesthetic and environmental impact that wind devices create, however in terms of domestic applications the environmental impact is considearably reduced.

Thermal solar energy

The thermal solar energy is rooted on the fact that it is possible to produce not only electrical but also thermal energy thanks to the solar irradiation. This is an alternative energy essentially employed in domestic environments for heating the water. Nowadays, the same hot water is also used to power the heating systems of the building, mainly adopting radiant floors technology. The conversion of the sun energy takes place in the solar collectors, usually located on a well oriented surface of the building. The system operation is simple: inside the collector, which is insulated at the back and protected superiorly with glass panes, there are pipes in which water flows. The fluid is heated by the sun and, before been supplied in the building, it is stored in the accumulator. This technique allows to fulfil the water need all day long. Again, as it is stated for solar panels, the solar collectors available on the market have a limited efficient because it remarkably varies depending on the climate conditions and the system employed. The current demand of this technology is stimulating the research and the development of cheaper and more reliable systems. Moreover, due to the discontinuity of the solar energy, the domestic thermal solar systems should be integrated with the traditional heating systems.

5.10 Communication

Nowadays high performances buildings may improve their appeal showing to the stakeholders the parameters about the energy they are producing, the amount of CO_2 they are restrain or the fossil fuels saving thanks the adoption of renewable resources they are employing. The performances communication contributes not only for the prestige of the construction but also to sensitise the people about the use of alternative resources reducing the environmental pollution. The communication must report the essential data, avoiding complex rates, must also be intuitive and accessible to everyone who wants to experience it. Likewise, the component of involvement is extremely important to make people aware and available to take advantage of this service. The device and the graphic design can change based on the different type of activities which take place in the building. The communication contents may be also associated with commercial advertisements or to entertain the passers-by with music or animations. The variety of the images and the videos is a strong attraction for the stakeholders who in this way are entertained and informed at the same time.

To fulfil this requirement there are different efficient solutions which all derive from “digital signage”. This technology assumes that the images, videos and texts are shown thanks to digital screens with different sizes. Compared to the traditional way of public communication, the use of Monitor LFD (Large Format Display), LED and the so-called “totems” are able to inform the users more dynamically and in a more engaging way. The totems are independent and compact elements which can be flexibly placed in the space because they do not need to be fixed to a wall. On the other hand, LFD and LED screens require a support to be attached to, compromising their ease of be moved. There are several aspects which may influence the right design and the feature of the screen. First of all the dimensions and the flexibility play a key role because, depending on the contents displayed and the view distance, small screen can be watched closely and vice versa. Hence, the sizes can vary a lot and generally they are between 22” to 105” wide. Depending on the place where they are located, they must guarantee the clear view of the contents both in outdoor and indoor environments. In addition, they require to resist against adverse weather conditions, keeping a waterproof and high temperatures resistance behaviour.

Another consideration deals with the operating costs which are directly related to the number of houses they are in use.

5.11 Durability

The requirement of durability is becoming indispensable for new construction to improve the building environmental sustainability and to reduce the costs of maintenance. Concerning precast concrete panels, ones again the key element is the core material employed in the construction of the panels: the concrete. Hence, if they are correctly casted and curried, thanks to their durable and low-maintenance concrete surfaces, precast concrete panels provide a long service life of the building cladding. In particular, the two main characteristics which the harden concrete must have are mechanical resistance and durability. The first one is treated in the specific paragraph while the second depends one several factors which are:

- Composition
- Depth of concrete cover
- Concrete exposure class
- Concrete curing time

Composition

The basic concrete constituents are cement, water, aggregates and potential chemical admixture. The cement is in charge of developing the mechanical resistance thanks to the chemical reactions with water. The water oversees the hydration of the cement, making the concrete paste workable. The aggregates are in charge of constituting the rigid skeleton of the concrete conglomerate, reducing the concrete shrinkage and contributing to mechanical resistance. The chemical admixtures confer to the concrete some extra characteristics according the different needs. They are not indispensable but become essential to obtain the best concrete paste from technological and economical prospective. Moreover, there are important parameters which must be always taken into account to cast a high durability concrete. The first one is the wa-

ter-to-cement ratio: the ideal ratio should be 0,5 which means that if the concrete contains 100 kg of cement, this implies that are used 50 l of water. Following this prescription, it is possible to obtain a workable concrete during its casting and it becomes mechanically resistant and compacted after its curing.

Coming up to the aggregates, the rule which links them to water is called the Lyse rule: it states that given the maximum diameter of the aggregate, the higher is the class of consistency required for the fresh concrete, the more is the amount of the water. It is also valid for a given workability of the concrete, the bigger is the maximum diameter of the aggregate, the lower is the need of water to achieve the fixed workability. In order to keep the concrete less porous and thus more durable, the granulometric distribution of the aggregate must be mixed. This means that using aggregates with various diameters it is possible to fill the gaps between aggregates more efficiently, allowing to obtain a high-density concrete with better mechanical resistance. To assess the granulometric distribution, it is employed the Fuller curve and it is described by the following formula: $\%P = (\sqrt{d}/D) \cdot 100$.

Depth of concrete cover

The suitable depth of concrete cover must always be guarantee in order to prevent the premature degradation of the reinforced concrete's steel bars. Indeed, the corrosion is triggered when the steel bars are not protected by the concrete cover and are directly exposed to external environment. Once the corrosion has been set up, the steel bars lose the compact oxide which surrounds them and, given that they are in contact with humidity and oxygen, they start to expand their volume as a result of the corrosion reaction. In the case of the concrete cover is design correctly, the bars immersed in the hardened concrete paste are passivate which means that they cannot be subjected to corrosion. This is due to the high pH of the concrete paste which, being higher than 11, allows the bars to be protected by corrosion. If the concrete is porous because it has been made with an high water-to-cement ratio and inappropriate concrete cover, its permeability allows water and corrosive substances to penetrate the protection layer and to decrease the pH level of the concrete paste below 10. This sets up the corrosion of the steel bars. Thus, a

thicker cover reduces the diffusion of CO_2 in the concrete, protecting it from carbonatation and maintaining a higher pH for a longer time period.

Concrete exposure class

To increase the concrete service life, the first concern of designers must be focused on the environmental conditions in which the concrete will be exposed. Taking into account the international codes, there is a similarity in terms of the employment of this method, but the nomenclature of the different standards changes from country to country. To make easier the example, it is considered the Italian codes UNI 11104 and UNI EN 206-1 which allow to identify the correct combination of exposure class depending on the different mechanisms of environmental degradation on the structures. The key aspects, reported also in the other international codes, is that the suitable class is defined starting from some parameters which are maximum water-to-cement ratio, minimum specified compressive strength (MPa) and minimum cement quantity (kg/m^3). The choice of the combination of exposure classes should be performed for all structural elements, based on their position in the construction. Moreover, the different concrete surfaces of a given structural element may be subject to different environmental actions. For instance, cladding systems are frequently subjected to freezing and thawing cycles, aggressive external substances and temperature changes. This implies that the exposure class must be sufficiently high to preserve the concrete intact.

Concrete curing time

The curing time is essential to obtain a long-durability concrete. It encompasses the operations which occur after the concrete casting and must assure optimal conditions for its grip and hardening. The target is to store the concrete paste saturated with water until the space is replaced by hydration products. The duration must last at least 7 days, or it must be extended until the concrete has reached 70% of the required compression resistance. In the case of precast concrete, all the manufacturing phases are conducted in the pant with the constant control of the parameters involved. The factors which influenced the curing are the environmental conditions

which are the temperature, the relative humidity and the wind speed. The normal curing conditions present the following figures: T= 20 °C, RH= 80%, W= 4,5 m/s. The industrial production allows also to provide the accelerated curing thanks to saturated steam at low and high pressure. Especially, sandwich panels must provide long-term durability both for the inside and outside concrete walls. For this reason, it is common to fix just the sealant material if the routine inspection has detected some degraded parts. Thanks to an appropriate curing time, it is possible to save money and time for extraordinary maintenance, reducing also the overall pollution.

Recoverability, reuse, recycle

Nearly 1.8 billion tons of construction and demolition waste (C&DW) are produced every year in China. Precast concrete constructions must be able to adapt to the changes required by modern society and, among them, the reduction of waste production is become crucially important. To achieve the principles of sustainable management of the wastes, it is indispensable that the concrete can be reached the most reduce amount of wastes destinated to the landfill. To better understand how the precast concrete can be involved in the logic of sustainable management of the wastes, it is important to briefly describe the pyramid of "waste hierarchy". It must specify that this definition is applicable to every kind of waste, including precast concrete. Starting from the bases of the pyramid, which correspond to the least favoured option, it can be found the wastes disposal when wastes are assigned to landfills, permanent storages and incineration without energy recovery. The second step is the energy recovery when wastes are turned into energy thanks to wastes incinerator. The third step is occupied by the recycling when wastes are reprocessed to obtain products, materials or substances to be used in their original function or for other purposes. The fourth step includes the reuse when the waste materials are reemployed after just being controlled, cleaned and repaired without further processing. Finally, at the top of the pyramid there is the prevention which consists in avoiding the production of wastes when possible.

Following this scheme, to improve the sustainability of the concrete, it is important that, at the moment of the end of live, the concrete layers of the precast concrete panels could be recycled

or reused. This happens if the structure has been carefully planned and designed, if the building has been maintained regularly and demolished following the correct procedures. The concrete that is recycled at the end of its life cycle, reducing its environmental impact, is recovered by construction and demolition waste (C&DW) and can be crushed and used as an aggregate. It is mainly used for the construction of the background and foundations of the roads, but a certain percentage can also be used to produce new concrete. The concrete can be reused in various ways either on a large scale and, in some situations, in its original forms. An example was to leave the structure intact, only modernizing the interior space and the cladding of the building. This approach preserves natural resources and avoids the environmental impact of waste disposal and the extraction, production and transport of new materials.

The reuse of precast concrete panels avoids the environmental impact associated with disposal and saves on material costs. According to a research carried out by Federbeton (Federbeton, 2009), a house made from recycled concrete panels can be three times more efficient from energetic point of view, and approximately 30-40% cheaper than an armed building built with new materials. Another recycling mode can be applied when concrete structures are built in precast units connected by bolts or welded joints, designed to be disassembled; units can be disassembled causing no damages. One of the most relevant advantages of precast concrete panels is the opportunity to disassemble the different units of the building to move them in another site. Another example is prefabricated buildings in which some units can be reused and the rest of the structure is crushed. The crushed concrete can be reused either as a roadbed or as an aggregate in the production of new concrete. The crushed concrete is generally used to make road infrastructure, parking areas, but also as filling material in excavations of pipes or in the foundations of buildings. It is generally more affordable than new materials.

Part III – The tool

6. PANdwich: THE DATABASE FOR PRECAST PANELS TECHNICAL SOLUTIONS

6.1 Who it is for

PANdwich, the database for precast panels technical solutions, is the final result of the Thesis. It stands as a practical tool proposed to lead the professionals towards the most suitable technical solutions which can fit the project involved. Hence, the database is intended for all the professionals, architects, engineers and technicians, who want to use a user-friendly support able to assist them in the broad and complex world of precast panels. It entails that it is referred to people who have the technical knowledge to interpret the specific features of the database input and output. It has been though as a service available online, so potentially employable worldwide. By using Pandwich, the project staff can easily choose a range of technical solutions, already selected to fulfil the latest requirements referred to the single parameter they are interest in researching. Moreover, this tool allows the professionals also to avoid to spend money and time by consulting some external consultants and experts to have additional opinions and recommendation about the best solutions. Following all the steps planned by database, the users can not only display the best solutions thay have been looking for but also receive a customise assistance by the PANdwich team in order to optimise the quality of the results and maximise their workflow.

6.2 What it is for

PANdwich has been developed to fulfil all the most relevant aspects related to the professionals' necessity to find the most suitable and efficient technical solutions for the design of precast panels. Hence, the first function of this consists in gathering a wide array of technical elements that can be chosen by the technicians in order to optimise their project. It is important to remind that all the solutions shown in the database meet the latest requirements both from architectural and engineering prospective. So, it is also a tool to verify the various technical components currently available on the market and employable in the projects. Given that the world of pre-

fabrication is considerably vast, PANdwich is a guide device which can assists the project staff in the choice of the technical solutions according to the final performance level they want to obtain from the panels. Moreover, it is important to underline that the database allows the professionals to deeply customize their choice thanks to the fact that they follow progressive steps able to narrow their research and archive the most accurate solutions. Another additional function consists in taking further technical assistance by the PANdwich team and there is also the opportunity to receive a design suggestion to optimise and speed up the professional work-flow. The last task is always elaborated by PANdwich specialists. These services have been hypothesised as a supplementary phase following the preliminary technical solution choice by querying the database.

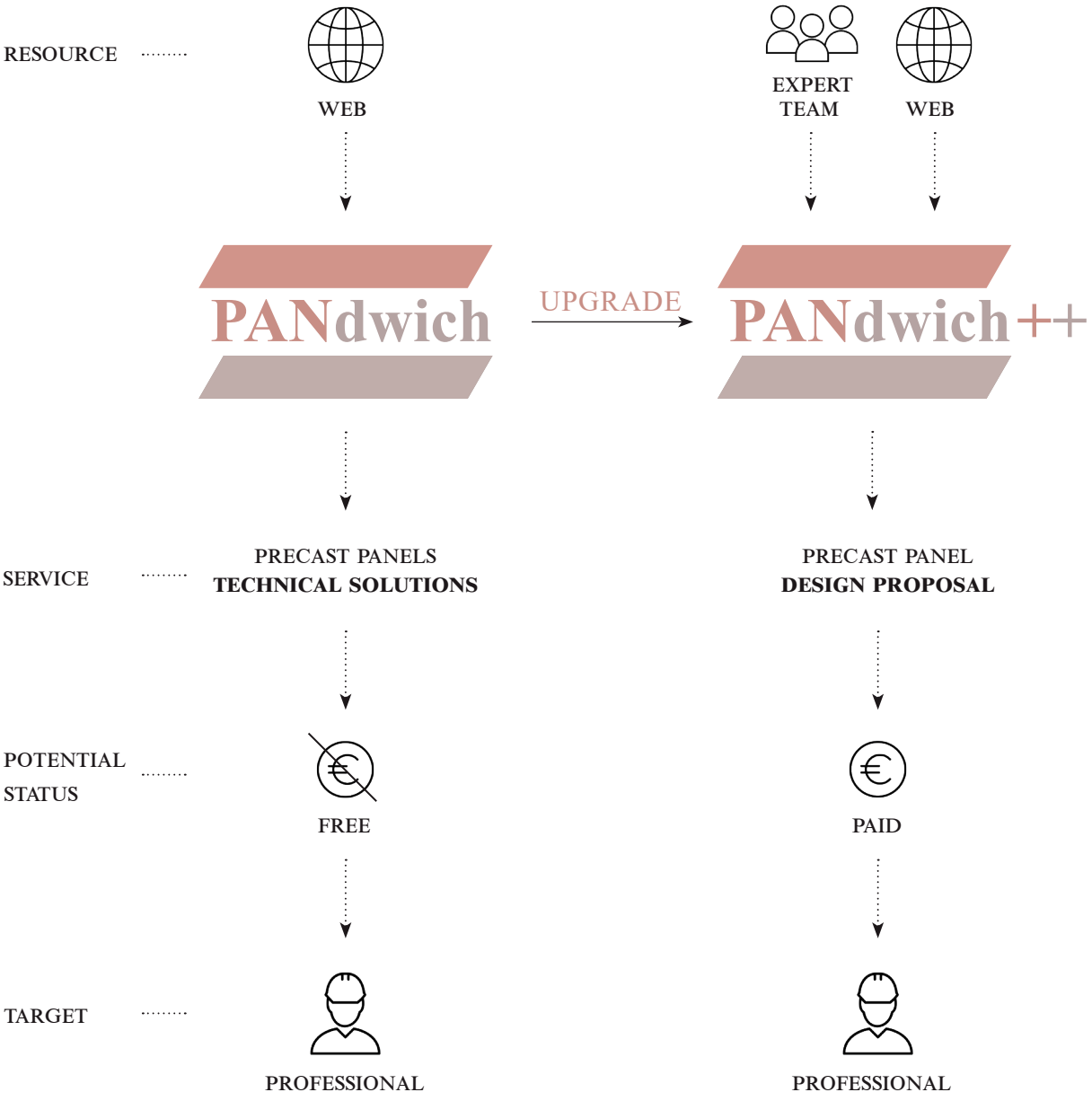
6.3 How it works

PANdwich has been designed to be an intuitive and easy-access tool, available online. Its operating principle is based on a progressive logic, divided into six consecutive steps that can be schematised as it follows:

1. sign in by browsing the PANdwich.com website,
2. answer to some simple questions to allow the database to understand the key context of the research,
3. choose the parameter the professionals would like to investigate,
4. choose the feature in which they are interested in,
5. let the database select the best technical solutions according to the rank scale
6. upgrade to PANdwich++ to receive extra services.

In a potential real application the tool is divided according to a free and a paid use of it. The professional interested in finding the most efficient technical solutions can utilize PANdwich for free running all the steps from 1 up to 5 once. In order to access to all the services, there is the possibility to upgrade the paid version, called PANdwich++, to receive extra assistance, access the entire database set and display a possible precast panel design solution elaborated

by the PANdwich's expert team. This team could be constituted by a prefabrication design company or a start-up which products innovative precast panels, providing a customised design service. The panel's design proposal integrates the database choice obtained in the previous part in a complete example of application. The panel characteristics have been already selected in order to fulfil the minimum requirements of precast concrete panels from architectural and engineering point of view. This extra service has been thought as an additional support for the professionals to find the most appropriate design solution. In order to clarify how the database works, it follows a distinction among input data, evaluation system and output data. The entire database workflow has been thought to be displayed as an online resource.



6.4 Input data

Once performed the sign in with one of the suggested ways, the system requires that the user answers a series of simple questions so that the database can understand the context in which it is intended to operate. The first input concerns the use of the building for which the design of precast panels is due. The system recognizes four types of uses that are office, residential, retail and industrial. The second question focuses on the typology of cladding system, and among these can be selected curtain wall, double skin, monolithic cladding, heavy panels/concrete panels, lightweight panels. Depending on the typology selected, the system will proceed to ask for an additional question to identify the specific sub-type of panel if provided by the database (for example, in the case of precast concrete panels, the system will ask to identify which of the six typologies present in the database the user is interested to). The third input macrocategory deals with the choice of systems, products and materials. PANdwich requires in which parameter the user would like to investigate among acoustic systems, acoustic insulation, finishes materials, weathertight, digital communication systems, energy production solutions, concrete types, IAQ solutions, shading systems & options and windows systems. After completing this section, the database provides the preliminary solutions available which fit the previous steps. For each solution it is possible to obtain more specific details about the product by clicking on the related icon. The last input requests to choose in which feature the professional is interested in the most. These features are related to the technical solutions previously visualised and they can be for example customization, aesthetic impact, cost, environmental impact and durability.

6.5 Rating system

As reported in the previous paragraph, once the professional has chosen the parameter that he would like to investigate, the database provides a series of the preliminary technical solutions. For each of them, it is possible to display the key characteristics which change from one to the other. Below them, follow additional features which change according to the different product selected. The database reports for each feature a grade expressed by a scale of black dots. The

assessment of the singular feature is already installed in PANdwich and it comes from the technical sheets issued by the productors. The grade expresses the level of performance that the singular feature is able to establish. In order to design the most intuitive rating system, it has been decided to associate a number of black dots to the related grades, according to a progressive logic. One dot corresponds to acceptable performance level, which means that it is able to fulfil the minimum requirements. Two, three, four and five dots are associate respectively to average, good, very good and excellent grades. The database rating algorithm is properly set up when the user decides in which feature he would like to refine the search to identify the most suitable technical solutions. The rating engine is projected to select and display the alternatives which have at least three points fulfilled out of five. After having queried the database, PANdwich shows the only technical solutions able to have at least good performances according to the feature chosen. It is a useful method to select and identify the most efficient solutions for precast panels.

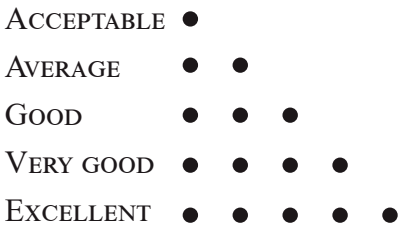


Fig. 6.1 The features grades expressed by a scale of black dots

6.6 Output data

The main output data are realised in the moment of the PANdwich progressive steps. After the completion of the three initial pats, sign in, answer simple question about the general context and identify the interested parameter, the database shows a preliminary list of technical solutions available, represented by different icons. For each of them, it is possible to visualise more details dealing with their name, appearance, key and secondary characteristics. The final outputs are displayed after having chosen the feature in which the professional is interested the most and having queried the database: they consist in a more accurate selection of technical solutions that can be immediately taken into account for the design of precast panels.

For the professionals who decide to upgrade PANdwich to PANdwich++ they can obtain further

outputs having at their disposal extra services. The main one is the reception of a precast panel design proposal elaborate by the PANdwich's expert team. Thanks to this service, it is possible to implement the database choice with a real application realised in a complete panel. Its characteristics have been already selected in order to fulfil the minimum requirements of precast concrete panels from architectural and engineering point of view.

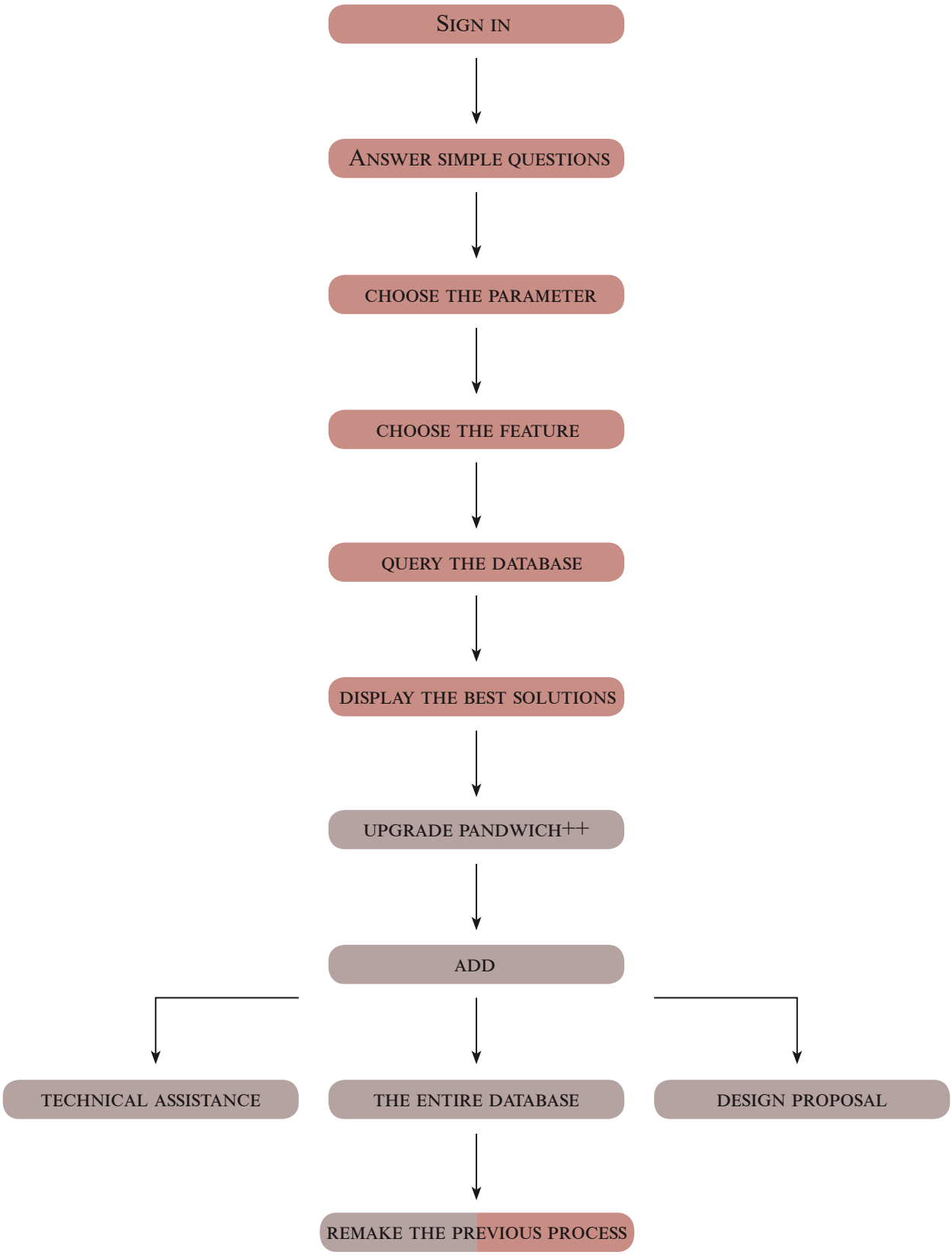
6.7 Graphical interface

The graphical interface of the database has been design accounting the principals of user-friendly display. All the contents are represented with stylised images to facilitate the understanding of the different steps' sequence. The two key elements that allow to achieve the easy interface are the use of specific colours and icons. Since the logo, the database employs just two colours, a soft red and grey, which are able to guide the user through the different passages of the database. In the same vain, the icons have been chosen to be clearly recognisable and associable to the feature they represent. The combination of the two key elements is displayed in representation of the outputs of technical solution. Here, the icon is placed across a square coloured according to the shade of the original red and grey. Each icon is related to a name of a solution and the entire list is arranged following a numeric ascending order. Moreover, when the user wants to obtain more details about a single solution, it is possible to click on the icon to pop up a card with the additional information. Hence, the link between the two steps is created by the same colour and icon used.

6.8 An example of application

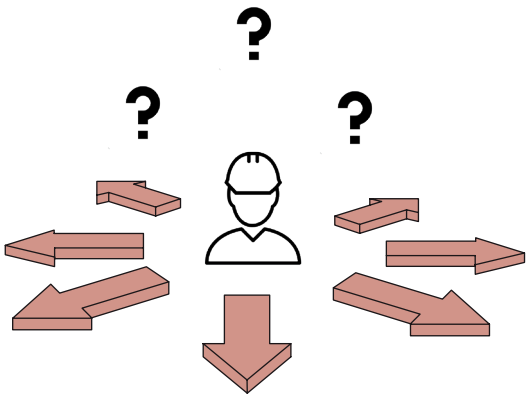
It follows an example of the complete application of PANdwich database. It is showed primarily the mechanism of the database until the achievement of the selected technical solutions, then there is the explication of the additional part, encompassed in the upgrade PANdwich++, in which there are extra services such as the personal assistance, the possibility of consulting the entire database and recaive a customised design proposal of a precast panel.

To sum up the framework of PANdwich, database for precast panels

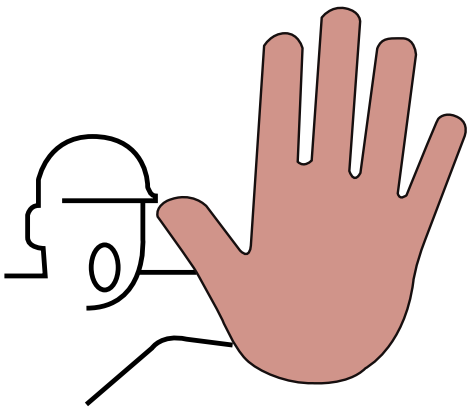


THE DATABASE FOR
PRECAST PANELS TECHNICAL SOLUTIONS

- ARE YOU A **PROFESSIONAL** WHO IS FIGHTING AGAINST THE **HUGE WORLD OF PRECAST PANELS**?



- WUOLD YOU WANT TO **STOP WASTING YOUR TIME AND MONEY** TO FIND THE BEST SOLUTION FITTING YOUR PROJECT?



- BROWSE

PANdwich.com

THE INTUITIVE **DATABASE** DEVELOPED TO ASSIST THOSE WHO ARE SEEKING A **WIDE ARRAY OF PRE-CAST PANEL TECHNICAL SOLUTIONS**, ACCORDING TO THE FEATURES THEY ARE INTERESTED IN DISPLAYING

- ## HOW TO USE PANdwich.com FOR FREE?

1 **Sign in for one free** research into the database

2 **Answer to some simple questions** to allow the database to understand the key context of the research

3 **Choose the parameter** you would like to investigate

4 **Choose the feature** in which you are interested in

5 **Let the database to select the best technical solutions** according to the rank scale

6 **Upgrade the paid version** to receive assistance, to access the entire database set and to dispay a possible design solution that can inspire you in your own project

LET'S START BACK

1

PANdwich.com

SIGN IN & START RESEARCHING

SIGN IN WITH FACEBOOK

SIGN IN WITH TWITTER

SIGN IN WITH GOOGLE

OR

Email address or username

Password

SIGN IN

2

ANSWER TO SOME SIMPLE QUESTIONS

WHICH IS THE FINAL USE OF THE BUILDING?

- ○ Offices
- ● Residencial
- ○ Retail
- ○ Industrial

WHICH IS THE TYPOLOGY OF CLADDING SYSTEM?

- ○ Curtain wall
- ○ Double skin
- ○ Monolithic cladding
- ● Heavy panels/concrete panels
- ○ Lightweight panels

WHICH IS THE TYPOLOGY OF PRECAST CONCRETE PANELS?

- ○ Monolithic
- ○ Ribed panel
- ● Sandwich panel
  - ● Solid wall panel
  - ● Window wall unit
- ○ Lightened panel
- ○ Spandrels
- ○ Mullions and column covers

3 Choose systems, products and materials

Which parameter would you like to investigate?

○ Thermal-acoustic systems

○ Noise reduction

● Finishes materials

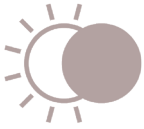
○ Air & Watertightness

○ Digital communication systems

○ Energy production solutions

○ Concrete types

○ IAQ solutions



○ Shading systems & options

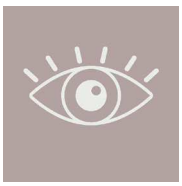
○ Windows systems

WELL DONE! THERE ARE 6 SOLUTIONS AVAILABLE

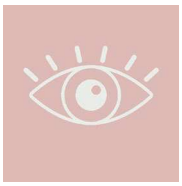
CLICK TO OBTAIN MORE DETAILS

01 Exposed aggregate

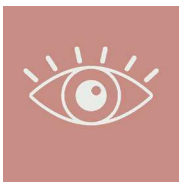
02 Smooth - acid etch



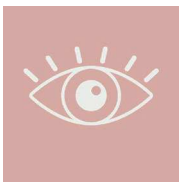
03 Form liners finish



04 Tooled finishes



05 Natural stone veneer finish



06 Brick face finish panels

EXPOSED AGGREGATE

01

Key characteristics:

Available colours: depending on the precaster

Others:

Customization:	● ● ○ ○ ○
Aesthetic impact:	● ● ● ○ ○
Cost:	● ● ○ ○ ○
Environmental impact:	● ● ● ● ○
Durability:	● ● ● ○ ○

SMOOTH - ACID ETCH

02

Key characteristics:

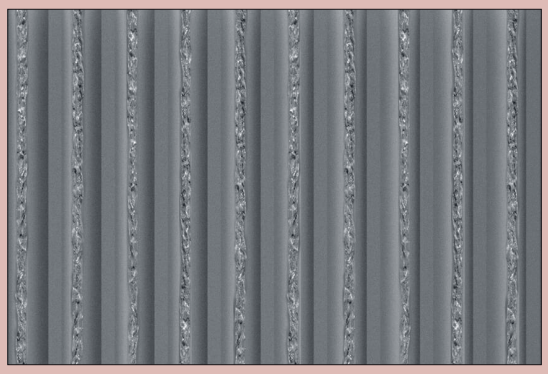
Available colours: depending on the precaster

Others:

Customization:	● ● ○ ○ ○
Aesthetic impact:	● ● ● ○ ○
Cost:	● ● ○ ○ ○
Environmental impact:	● ● ● ● ○
Durability:	● ● ● ○ ○

FORM LINERS FINISH

03



Key characteristics:

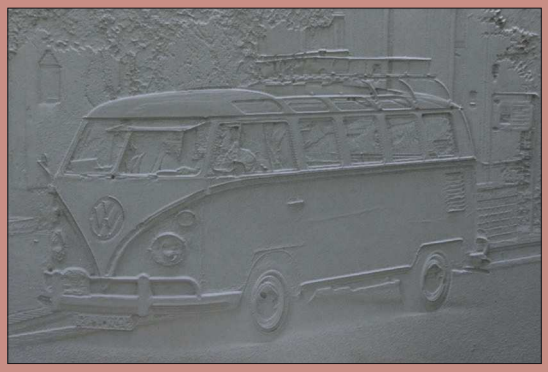
Available colours: depending on the precaster

Others:

Customization:	● ● ● ○ ○
Aesthetic impact:	● ● ● ● ○
Cost:	● ● ● ○ ○
Environmental impact:	● ● ● ● ○
Durability:	● ● ● ○ ○

TOOLED FINISHES

04



Key characteristics:

Available colours: generally the same of concrete surface

Others:

Customization:	● ● ● ● ●
Aesthetic impact:	● ● ● ● ●
Cost:	● ● ● ● ○
Environmental impact:	● ● ● ● ○
Durability:	● ● ● ○ ○

NATURAL STONE VENEER FINISH

05

Key characteristics:

Available colours: depending on the natural stones

Others:

Customization:	● ● ● ● ●
Aesthetic impact:	● ● ● ● ○
Cost:	● ● ● ● ○
Environmental impact:	● ● ● ● ○
Durability:	● ● ● ● ●

BRICK FACE FINISH PANELS

06

Key characteristics:

Available colours: depending on the bricks

Others:

Customization:	● ● ● ● ●
Aesthetic impact:	● ● ● ● ○
Cost:	● ● ● ○ ○
Environmental impact:	● ● ● ● ○
Durability:	● ● ● ● ○

4 Choose the feature

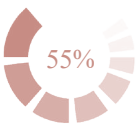
IN WHICH FEATURE ARE YOU INTERESTED IN THE MOST?*

- ● Customization
- ○ Aesthetic impact
- ○ Cost
- ○ Environmental impact
- ○ Durability

* The search engine is projected to select and display the alternatives which have at least three points fulfilled out of five. The number of points correspond to the performances provided by the technical element. The rank is organised following the logic below:

Acceptable	●
Average	● ●
Good	● ● ●
Very good	● ● ● ●
Excellent	● ● ● ● ●

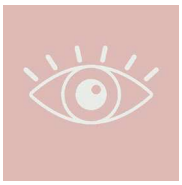
5 Query of the database



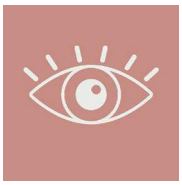
LOADING THE BEST SOLUTIONS...

THE BEST 4 SOLUTIONS ARE WAITING FOR YOU! ENJOY!

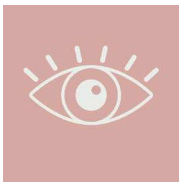
03 FORM LINERS FINISH



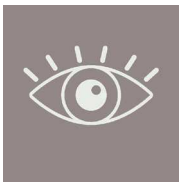
04 TOOLED FINISHES



05 NATURAL STONE VENEER FINISH



06 BRICK FACE FINISH PANELS



6 Upgrade PANdwich++

WOULD YOU LIKE TO UPGRADE TO PANdwich++?

Upgrade PANdwich++

Continue with free version

- ## Excellent!

Thanks to your subscription to Pandwich++ you are got involved in extra services provided directly from the operative platform:

I **Technical assistance** by the call centre specialists

II Consult the **entire database for every parameter**

III **Receive the design proposals** to optimise your workflow and your inspiration

TRY NOW BACK

I Technical assistance

WOULD YOU LIKE TO CONTACT THE OPERATOR SPECIALISTS?

Select the way you wish

+39 800 000 000

PANdwich++

II CONSULT THE ENTIRE DATABASE

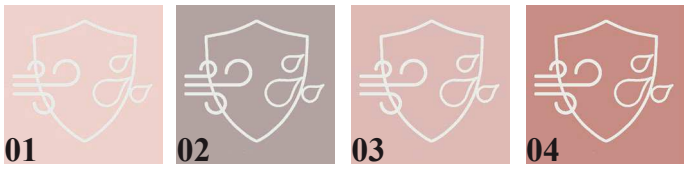
WOULD YOU LIKE TO CONSULT THE ENTIRE BATABASE FOR EVERY PARAMETER?

CLICK TO OBTAIN MORE DETAILS

THERMAL-ACOUSTIC SYSTEMS

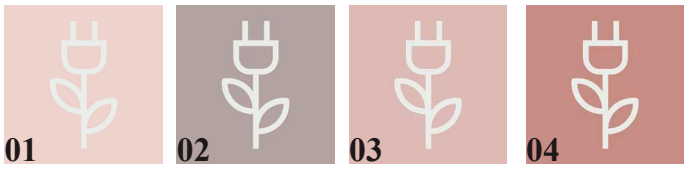
NOISE REDUCTION

AIR & WATERTIGHTNESS

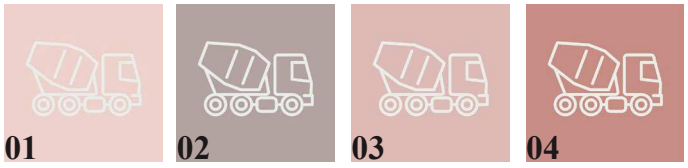


DIGITAL COMMUNICATION SYSTEMS

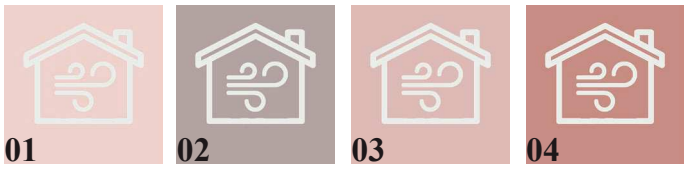
ENERGY PRODUCTION SOLUTIONS



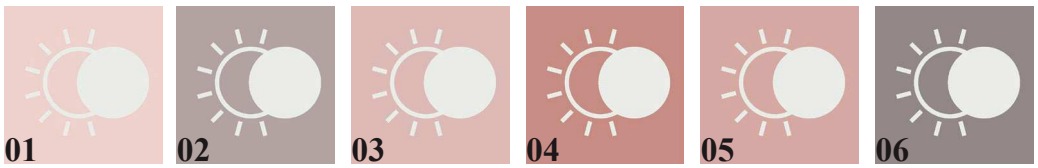
CONCRETE TYPES



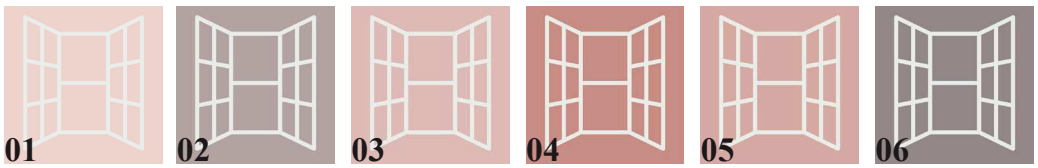
IAQ SOLUTIONS



SHADING SYSTEMS & OPTIONS



WINDOWS SYSTEMS



LIGHTWEIGHT FLEXIBLE GLASS MINERAL WOOL QUILT

01

Key characteristics:

Available thickness (cm): 5 - 7,5 - 10

Thermal conductivity (W/mK): 0,044

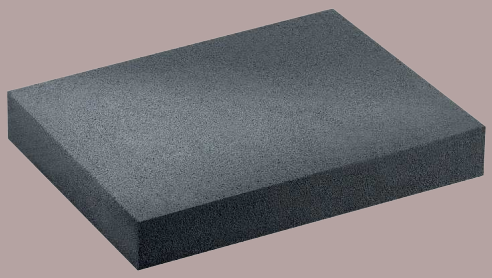
Density (Kg/m^3): 10

Others:

Lightness:	●	●	●	●	●
High temperature resistance:	●	●	●	●	○
Recyclability:	●	●	○	○	○
Environmental impact:	●	●	●	●	○
Durability:	●	●	●	○	○

CELLULAR GLASS - SLABS

02



Key characteristics:

Available thickness (cm): 6-7-8-9-10-11-12-13-14-15-16-17-18

Thermal conductivity (W/mK): 0,038

Density (Kg/m^3): 45

Others:

Lightness:	●	●	●	○	○
High temperature resistance:	●	●	●	●	○
Recyclability:	●	●	●	●	●
Environmental impact:	●	●	●	○	○
Durability:	●	●	●	●	○

SEMI-RIGID SLABS OF GLASS MINERAL WOOL

03

Key characteristics:

Available thickness (cm): 6,5 - 7,5 - 8,5 - 10 - 12,5 - 15

Thermal conductivity (W/mK): 0,037

Density (Kg/m3): 45

Others:

Lightness:	●	●	●	○	○
High temperature resistance:	●	●	●	●	●
Recyclability:	●	●	○	○	○
Environmental impact:	●	●	●	●	○
Durability:	●	●	●	○	○

ROCKWOOL INSULATION

04

Key characteristics:

Available thickness (cm): 6-7,5-10

Thermal conductivity (W/mK): 0,035

Density (Kg/m3): 45

Others:

Lightness:	●	●	●	○	○
High temperature resistance:	●	●	●	●	●
Recyclability:	●	●	●	○	○
Environmental impact:	●	●	●	●	○
Durability:	●	●	●	●	●

PIR INSULATION

05

Key characteristics:

Available thickness (cm): 5 -6-7-7,5-10

Thermal conductivity (W/mK): 0,021

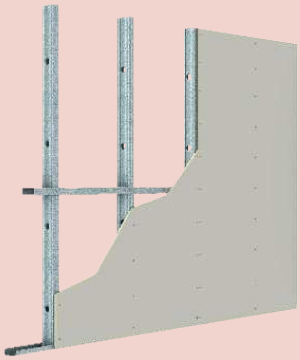
Density (Kg/m3): 11

Others:

Lightness:	●	●	●	●	●
High temperature resistance:	●	●	●	●	●
Recyclability:	●	●	○	○	○
Environmental impact:	●	●	●	●	○
Durability:	●	●	○	○	○

STUD SYSTEM WITH SINGLE GYPSUM PLASTERBOARD

01



Key characteristics:

Available stud thickness (cm): 7,5 - 10

Available plasterboard thickness (cm): 1,25

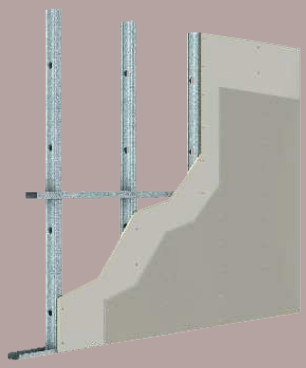
Rw (dB): 45

Others:

Installation speed:	●	●	●	●	●
Fire resistance:	●	●	●	●	○
Recyclability:	●	●	●	○	○
Environmental impact:	●	●	●	○	○
Shock resistance:	●	●	○	○	○

STUD SYSTEM WITH DOUBLE GYPSUM PLASTERBOARD

02



Key characteristics:

Available stud thickness (cm): 7,5 - 10

Available plasterboard thickness (cm): 1,25x2

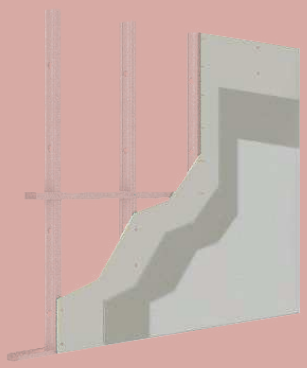
Rw (dB): 47

Others:

Installation speed:	●	●	●	○	○
Fire resistance:	●	●	●	●	●
Recyclability:	●	●	●	○	○
Environmental impact:	●	●	●	○	○
Shock resistance:	●	●	●	●	○

STUD SYSTEM WITH TRIPLE GYPSUM PLASTERBOARD

03



Key characteristics:

Available stud thickness (cm): 7,5 - 10

Available plasterboard thickness (cm): 1,25x3

Rw (dB): 50

Others:

Installation speed:	●	●	●	●	○
Fire resistance:	●	●	●	●	●
Recyclability:	●	●	●	○	○
Environmental impact:	●	●	●	○	○
Shock resistance:	●	●	●	●	●

ACRYLIC SEALANT

01

Key characteristics:

Density (Kg/m3): 1,76

Thermal resistance (°C): -30 +80

Workability (min): 10

Others:

Corrosivity:	●	○	○	○	○
UV resistance:	●	●	●	●	○
Recyclability:	○	○	○	○	○
Curing speed:	●	●	●	●	●
Durability:	●	●	●	●	○

POLYURETHANE SEALANT

02

Key characteristics:

Density (Kg/m3): 1,3

Thermal resistance (°C): -30 +80

Workability (min): 60

Others:

Corrosivity:	●	○	○	○	○
UV resistance:	●	●	●	○	○
Recyclability:	○	○	○	○	○
Curing speed:	●	●	●	●	○
Durability:	●	●	●	●	○

NEUTRAL SEALANT

03

Key characteristics:

Density (Kg/m3): 1,52

Thermal resistance (°C): -50 +180

Workability (min): 10

Others:

Corrosivity:	●	○	○	○	○
UV resistance:	●	●	●	●	●
Recyclability:	○	○	○	○	○
Curing speed:	●	●	●	●	○
Durability:	●	●	●	○	○

HYBRID SEALANT

04

Key characteristics:

Density (Kg/m3): 1,51

Thermal resistance (°C): -50 +90

Workability (min): 10

Others:

Corrosivity:	●	●	○	○	○
UV resistance:	●	●	●	●	○
Recyclability:	○	○	○	○	○
Curing speed:	●	●	●	○	○
Durability:	●	●	●	●	○

PHOTOVOLTAIC SHADINGS

01

Key characteristics:

Screen size (″): 46 to 55

Thermal resistance (°C): -30 +50

Certification: IP56

Others:

People attraction:	● ● ● ● ○
Frexibility:	● ● ○ ○ ○
Efficiency:	● ● ● ● ○
Environmental impact:	● ● ○ ○ ○
Durability:	● ● ● ○ ○

PHOTOVOLTAIC FACADE

02

Key characteristics:

Screen size (″): 32 to 34

Thermal resistance (°C): -30 +40

Certification: IP55

Others:

People attraction:	● ● ● ● ○
Frexibility:	● ● ● ● ●
Efficiency:	● ● ● ● ○
Environmental impact:	● ● ○ ○ ○
Durability:	● ● ● ○ ○

PHOTOVOLTAIC WINDOWS

03

Key characteristics:

Screen size (″): 40 to 46

Thermal resistance (°C): -30 +50

Certification: IP55

Others:

People attraction:	● ● ○ ○ ○
Frexibility:	● ● ○ ○ ○
Efficiency:	● ● ● ● ○
Environmental impact:	● ● ○ ○ ○
Durability:	● ● ● ● ●

PHOTOVOLTAIC SHADINGS

01

Key characteristics:

Recommended max lenght: double windows area

Opacity range (%): up to 100

Panel tilt (°): 30 to 90

Others:

Customization:	● ● ○ ○ ○
Integrability:	● ● ● ○ ○
Efficiency:	● ● ○ ○ ○
Environmental impact:	● ● ● ○ ○
Durability:	● ● ● ● ○

PHOTOVOLTAIC FACADE

02

Key characteristics:

Recommended max lenght: /

Opacity range (%): up to 100

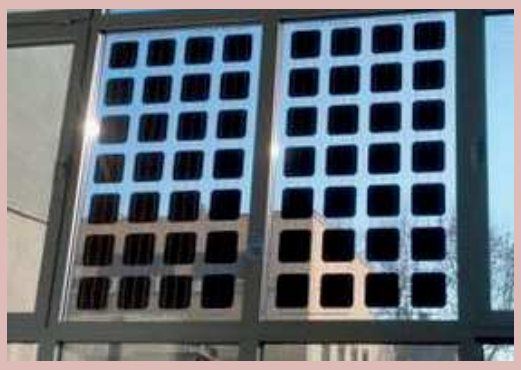
Panel tilt (°): 0

Others:

Customization:	● ● ● ● ○
Integrability:	● ● ● ● ○
Efficiency:	● ● ○ ○ ○
Environmental impact:	● ● ● ○ ○
Durability:	● ● ● ● ○

PHOTOVOLTAIC WINDOWS

03



Key characteristics:

Recommended max lenght: /

Opacity range (%): up to 60

Panel tilt (°): 0 to 30

Others:

Customization:	● ● ○ ○ ○
Integrability:	● ● ● ○ ○
Efficiency:	● ● ○ ○ ○
Environmental impact:	● ● ● ○ ○
Durability:	● ● ● ● ○

PHOTOVOLTAIC PARAPETS

04

Key characteristics:

Recommended max lenght: /

Opacity range (%): up to 100

Panel tilt (°): 0 to 30

Others:

Customization:	● ● ● ○ ○
Integrability:	● ● ● ○ ○
Efficiency:	● ● ● ○ ○
Environmental impact:	● ● ● ○ ○
Durability:	● ● ● ● ○

CONCRETE TYPES

Light Concrete

01

Key characteristics:

Cement: clinker, pozzolana (35-55%), blast furnace slag (35-95%)

Aggregate: expanded clay, expanded polystyrene, pumice, vulcanite

Rck (MPa): 10 to 50

Density (Kg/m^3): 1000 to 1800

Others:

Lightness:	● ● ● ● ●
High temperature resistance:	● ● ● ● ○
Recyclability:	● ● ● ○ ○
Environmental impact:	● ● ● ● ○
Durability:	● ● ● ● ○

High Performance Light Concrete:

02

Key characteristics:

Cement: clinker, pozzolana (35-55%), blast furnace slag (35-95%)

Aggregate: expanded clay, expanded polystyrene, pumice, vulcanite

Rck (MPa): 50

Density (Kg/m^3): 1800

Others:

Lightness:	● ● ● ● ○
High temperature resistance:	● ● ● ● ●
Recyclability:	● ● ● ○ ○
Environmental impact:	● ● ● ○ ○
Durability:	● ● ● ● ○

CONCRETE TYPES

C&D CONCRETE

03

Key characteristics:

Cement: clinker, pozzolana (35-55%), blast furnace slag (35-95%)

Aggregate: generic demolition waste rubble, concrete waste

Rck (MPa): 15 to 25

Density (Kg/m^3): 2150 to 2700

Others:

Lightness:	●	●	○	○	○
High temperature resistance:	●	●	●	○	○
Recyclability:	●	●	○	○	○
Environmental impact:	●	●	●	●	○
Durability:	●	●	●	○	○

MINERALISED WOOD CONCRETE (MWC)

04

Key characteristics:

Cement: clinker

Aggregate: wood wastes from woodworking activities

Rck (MPa): up to 50

Density (Kg/m^3): 550

Others:

Lightness:	●	○	○	○	○
High temperature resistance:	●	●	●	●	○
Recyclability:	●	●	●	○	○
Environmental impact:	●	●	○	○	○
Durability:	●	●	●	●	○

Low VOC paint

01

Key characteristics:

Low VOC paints emit low rate of volatile organic compounds; the secondary emissions of VOCs are not considered.

Others:

Toxicity:	● ● ○ ○ ○
Aesthetic impact:	● ● ● ○ ○
Cost:	● ● ○ ○ ○
Time:	● ● ● ○ ○
Durability:	● ● ● ● ○

Zero VOC paint

02

Key characteristics:

Zero VOC paints do not emit volatile organic compounds; this does not exclude the presence of harmful solvents and additives.

Others:

Toxicity:	● ● ● ● ○
Aesthetic impact:	● ● ● ● ○
Cost:	● ● ○ ○ ○
Time:	● ● ● ○ ○
Durability:	● ● ● ● ○

INDOOR PLANTS

03

Key characteristics:

Indoor plants, such as Aloe Vera, Pothos, Peace Lilly, Dracaena, Sansevieria, Dracaena, Rubber Fig, contribute to keep the indoor air clean by absorbing the harmful pollutants, such as formaldehyde.

Others:

Toxicity:	● ● ○ ○ ○
Aesthetic impact:	● ● ● ○ ○
Cost:	● ● ○ ○ ○
Time:	● ● ● ○ ○
Durability:	● ● ● ● ○

INDOOR MOSS WALL

04

Key characteristics:

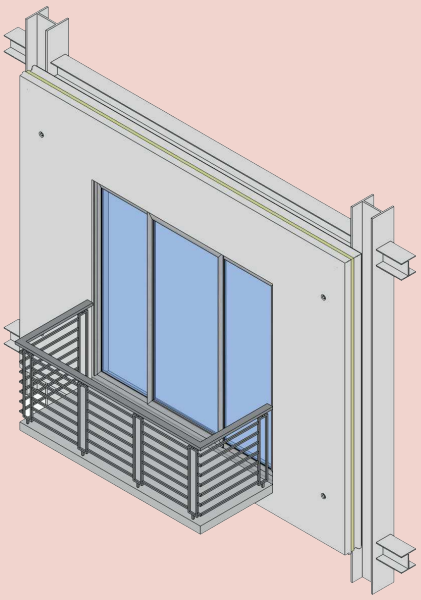
Indoor moss walls partially contribute to keep the indoor air healthier but they are effective especially for the psychological point of view.

Others:

Toxicity:	● ● ● ○ ○
Aesthetic impact:	● ● ● ○ ○
Cost:	● ● ● ○ ○
Time:	● ● ● ○ ○
Durability:	● ● ● ● ○

Balcony

01

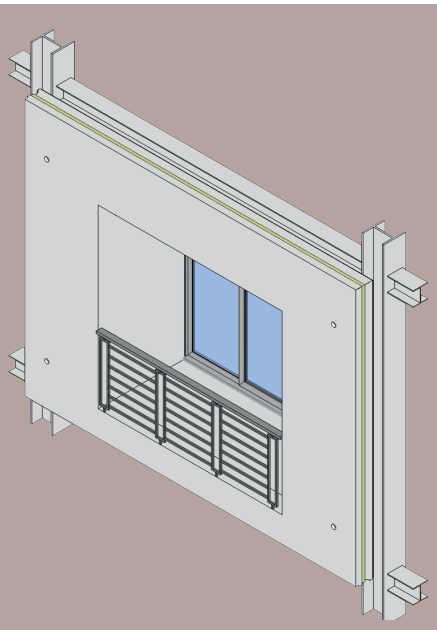


Others:

Customization:	● ● ● ● ○
Aesthetic impact:	● ● ● ○ ○
Cost:	● ● ● ○ ○
Time:	● ● ○ ○ ○
Durability:	● ● ● ● ○

Loggia

02

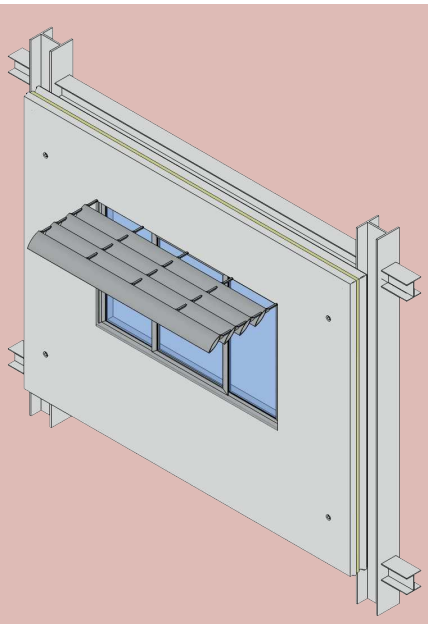


Others:

Customization:	● ● ○ ○ ○
Aesthetic impact:	● ● ● ○ ○
Cost:	● ● ● ○ ○
Time:	● ● ○ ○ ○
Durability:	● ● ● ● ●

HORIZONTAL SUNSHADING

03

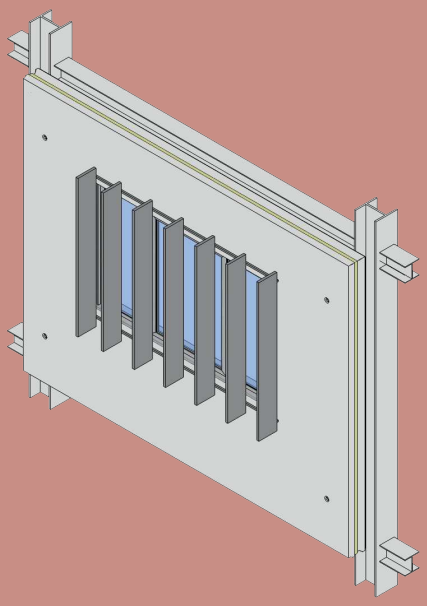


Others:

Customization:	●	●	●	●	○
Aesthetic impact:	●	●	●	○	○
Cost:	●	●	●	○	○
Time:	●	●	○	○	○
Durability:	●	●	●	●	●

VERTICAL SUNSHADING

04

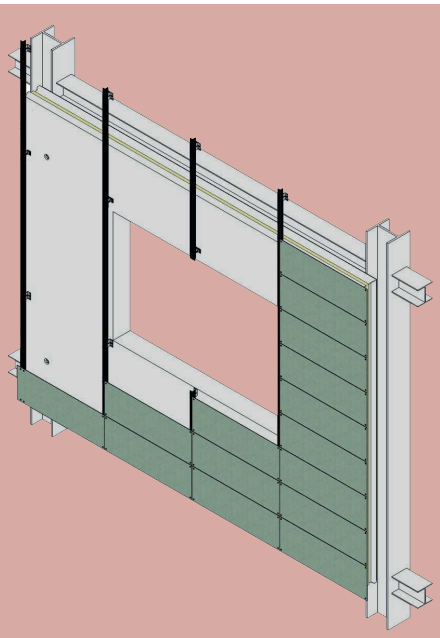


Others:

Customization:	●	●	●	●	○
Aesthetic impact:	●	●	●	○	○
Cost:	●	●	●	○	○
Time:	●	●	○	○	○
Durability:	●	●	●	●	●

VENTILATED FAÇADE

05

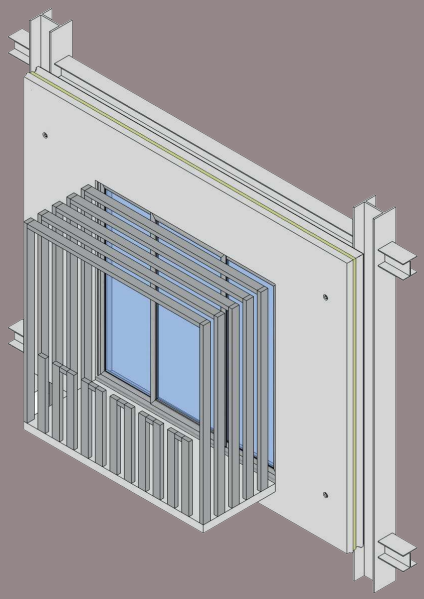


Others:

Customization:	●	●	●	●	●
Aesthetic impact:	●	●	●	●	○
Cost:	●	●	●	●	○
Time:	●	●	●	●	●
Durability:	●	●	●	●	○

HYBRID

06



Others:

Customization:	●	●	●	●	●
Aesthetic impact:	●	●	●	●	○
Cost:	●	●	●	●	○
Time:	●	●	●	●	○
Durability:	●	●	●	●	●

DOUBLE GLAZING

01

Key characteristics:

Double glazing is the combination of two parallel glass panes separated by a gap. The gap can be filled with gases such as Argon. They are widely used to improve the thermal and acoustic comfort.

Others:

Insulation:	● ● ● ● ○
Aesthetic impact:	○ ○ ○ ○ ○
Cost:	● ● ● ○ ○
Recyclability:	● ● ● ○ ○
Durability:	● ● ● ● ○

TRIPLE GLAZING

02

Key characteristics:

Triple glazing is the combination of three parallel glass panes separated by two gaps. The additional layer of glass allows to improve the thermal and acoustic insulation compared to the double glazing.

Others:

Insulation:	● ● ● ● ●
Aesthetic impact:	○ ○ ○ ○ ○
Cost:	● ● ● ● ●
Recyclability:	● ● ● ○ ○
Durability:	● ● ● ● ●

WOOD FRAME WINDOW

03

Key characteristics:

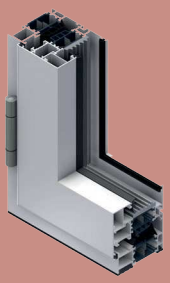
Wood frame windows have a long tradition of application and they are still broadly used thanks to their aesthetic, recyclability and efficient features. They need frequent maintenance.

Others:

Insulation:	● ● ● ● ●
Aesthetic impact:	● ● ● ● ●
Cost:	● ● ● ● ●
Recyclability:	● ● ● ● ○
Durability:	● ● ● ○ ○

ALUMINUM FRAME WINDOW

04



Key characteristics:

Aluminium frame windows can be easily customised in size and coating colours thanks to the inherent properties of the metal. It is also light and resistant but it has a low insulation efficiency.

Others:

Insulation:	● ● ● ○ ○
Aesthetic impact:	● ● ● ● ○
Cost:	● ● ● ○ ○
Recyclability:	● ● ● ● ○
Durability:	● ● ● ● ○

PVC FRAME WINDOW

05

Key characteristics:

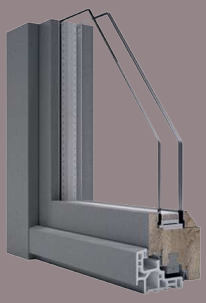
PVC frame windows are largely employed for their versatility and customisation. At end of service life, they can be easily recycled. Generally, they are the cheapest solution.

Others:

Insulation:	● ● ● ○ ○
Aesthetic impact:	● ● ● ○ ○
Cost:	● ● ○ ○ ○
Recyclability:	● ● ● ● ●
Durability:	● ● ● ● ○

HYBRID FRAME WINDOW

06



Key characteristics:

Hybrid frame windows allow to combine the advantages of two different materials in a single solution. The most popular application is made by aluminium and wood. They are expensive and hard to be recycled.

Others:

Insulation:	● ● ● ● ●
Aesthetic impact:	● ● ● ● ○
Cost:	● ● ● ● ●
Recyclability:	● ○ ○ ○ ○
Durability:	● ● ● ● ○

III RECEIVE THE DESIGN PROPOSAL

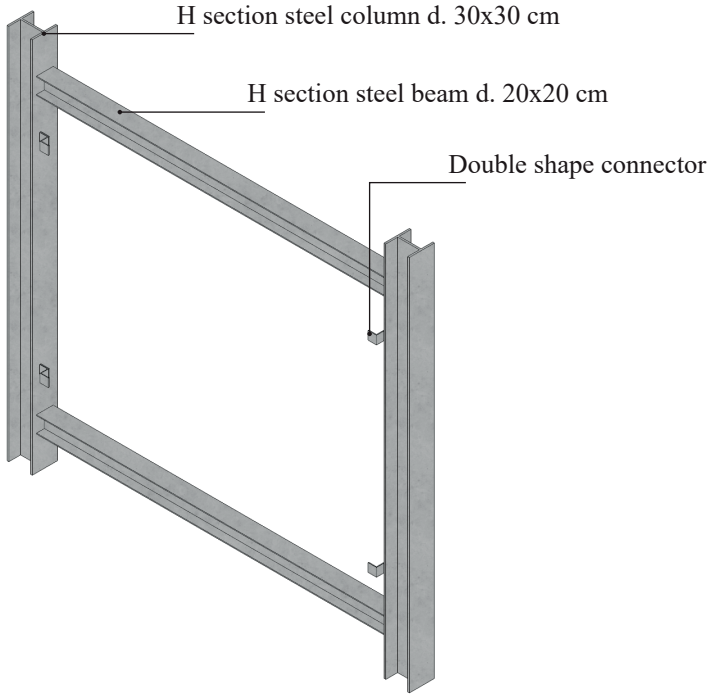
WOULD YOU LIKE TO OPTIMISE YOUR WORKFLOW AND INSPIRATION?

The suggestions for your design start from the basic characteristics of the panel. The characteristics have been already selected in order to fulfil the minimum requirements of precast concrete panels from architectural and engineering point of view. In case of need, the experts can help you to adapt the proposal to your specific aim.

A	B	C1,2	D	E	F
Structure	Connection	Dimensions	Stratigraphy	Concrete features	Fire resistance

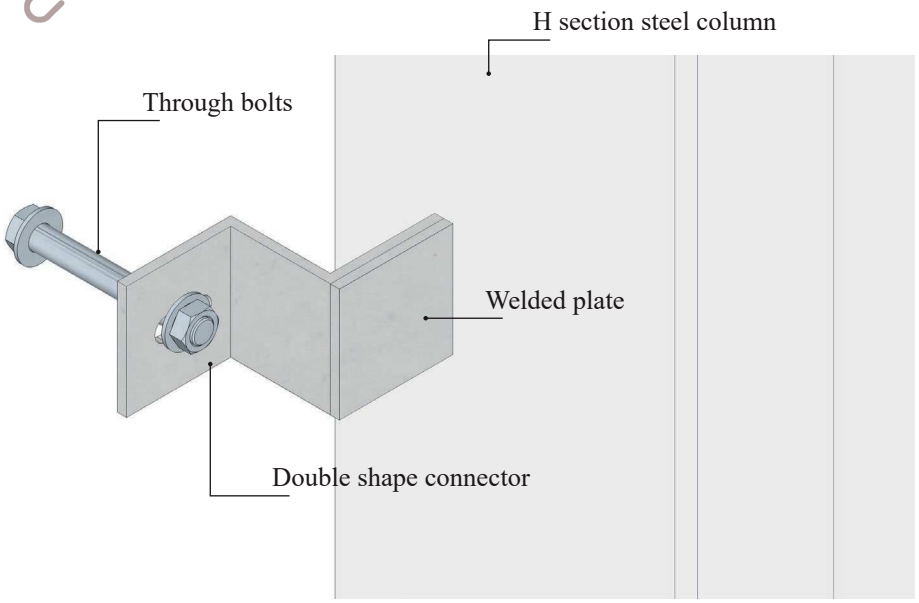
STEEL STRUCTURE

A



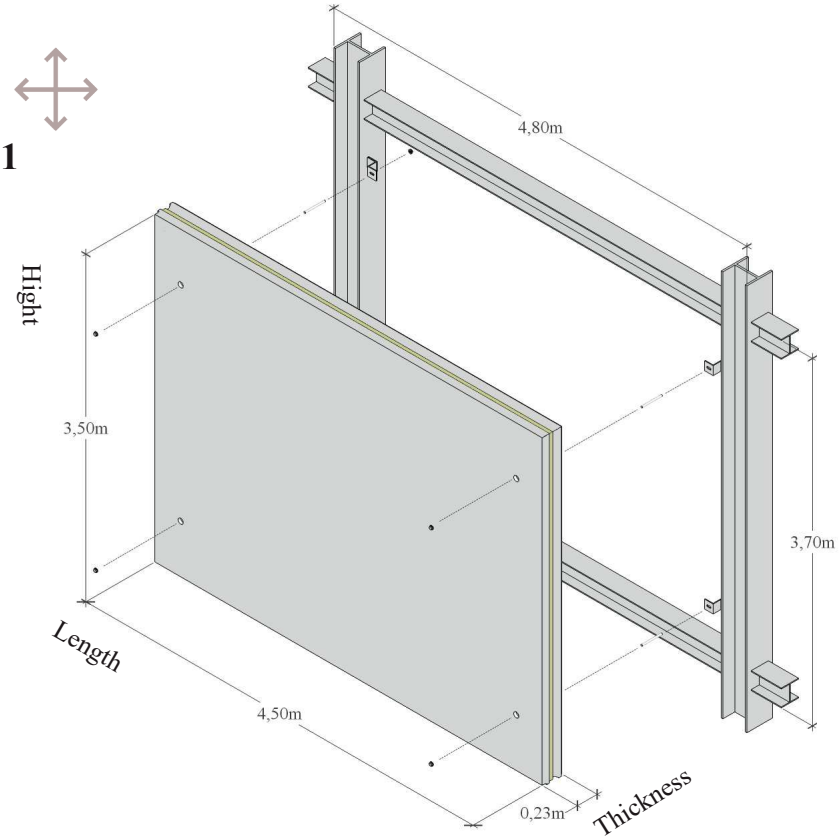
DOUBLE SHAPE CONNECTOR

B



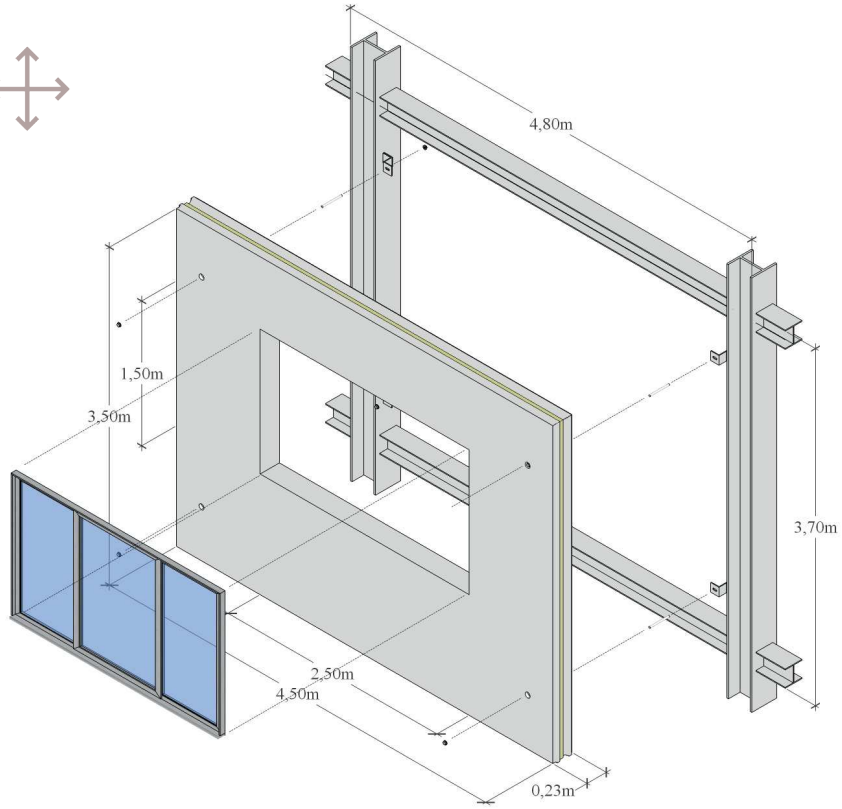
DIMENTIONS_ OPAQUE PANNEL

C1



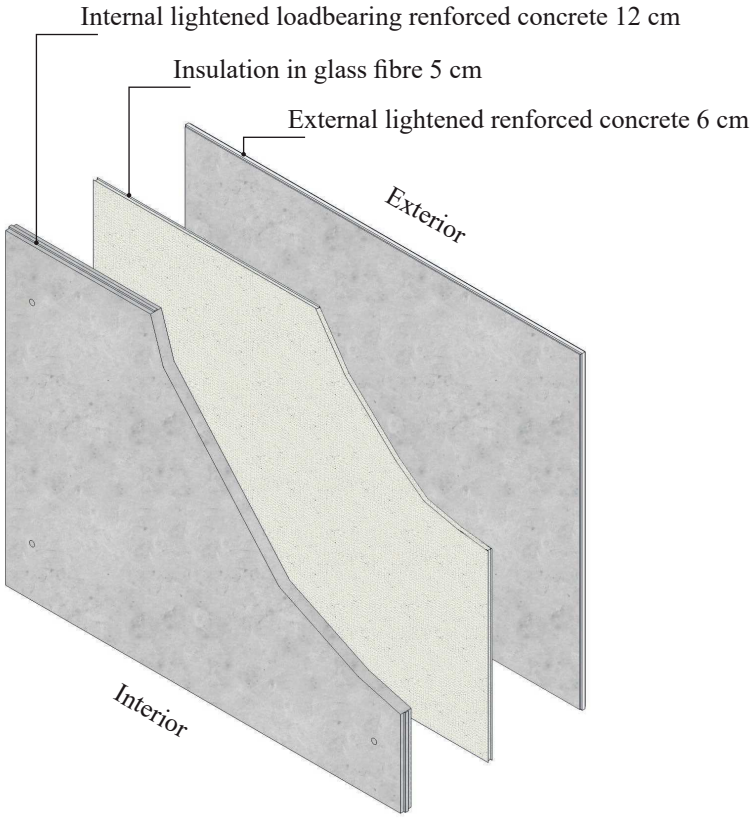
DIMENTIONS_ WINDOW PANNEL

C2



STRATIGRAPHY

D



Concrete features

E

- *Internal lightened loadbearing renforced concrete*

  Typology: SCC (self compacting concrete)

  Density: 2200 Kg/m2

  Rck : 45 MPa

  Water-to-cement: low ratio

  Fillers and aggregates max diameter: 16 mm

- *External lightened renforced concrete*

  Typology: SCLC (self compacting light concrete)

  Density: 1000 Kg/m2

  Rck : 10 MPa

Fire resistance

F

Resistance class: A1*

*According to the ISO 1182 a construction element assembled by concrete and glass fibre does not request specific fire tests and it is classified as A1.

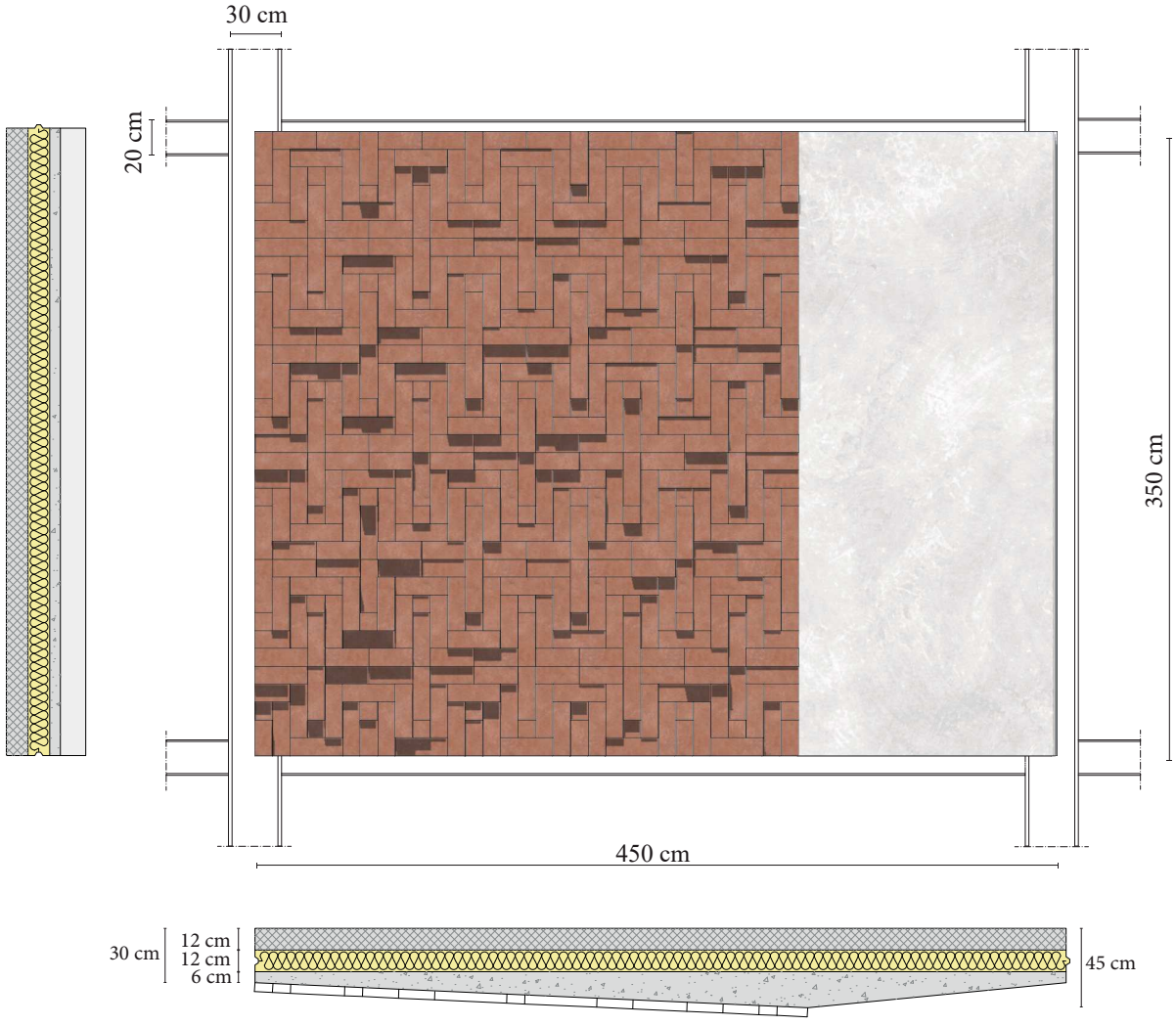
WHICH KIND OF PRECAST CONCRETE PANEL WOULD YOU LIKE TO DISPLAY?

○ Window wall units

● Solid wall panels

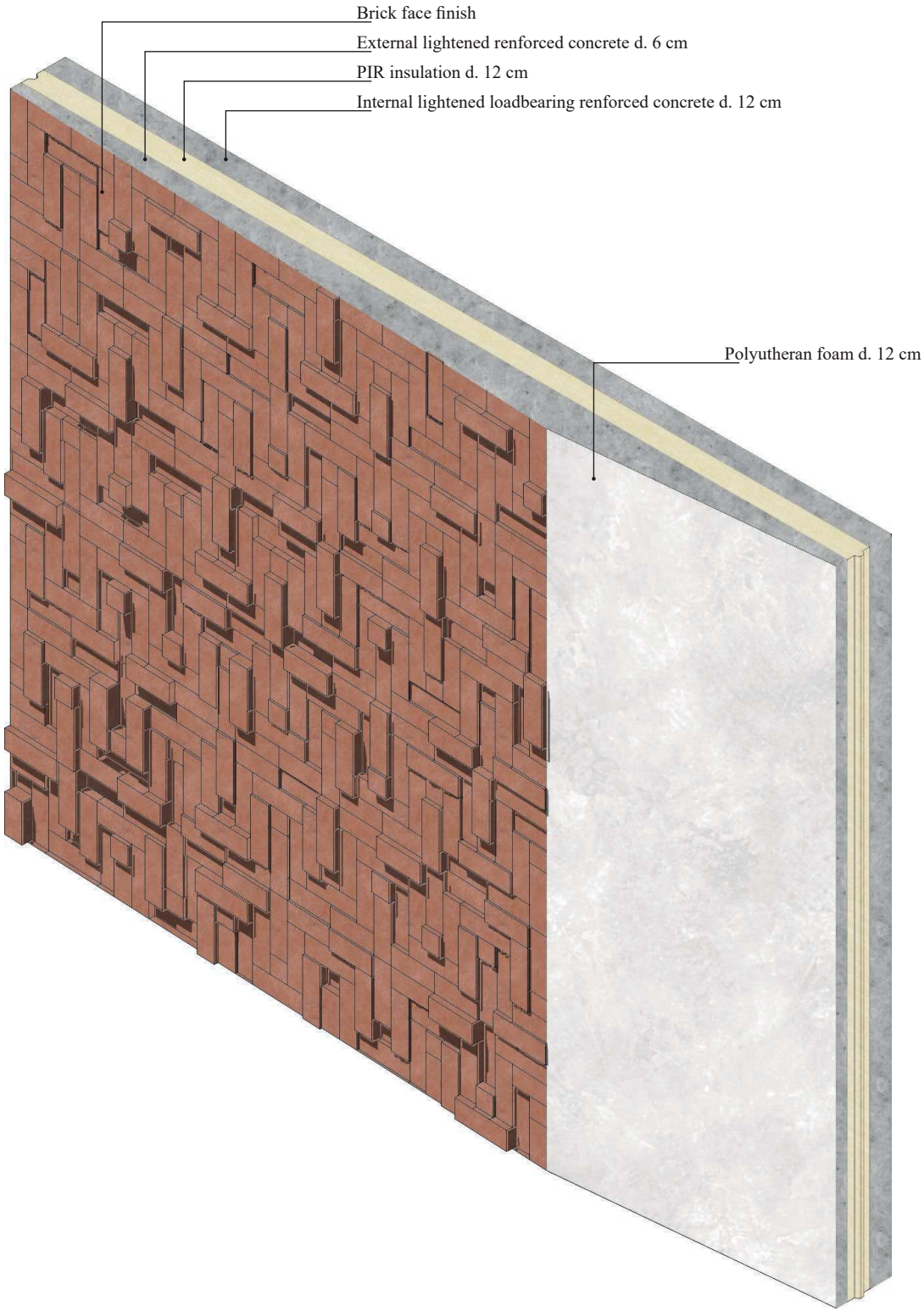
DESIGN PROPOSAL

PANEL FRONT VIEW AND CROSS SECTIONS



Scale 1:40

Panel isometric view



7. CONCLUSIONS

The steps of the Thesis have illustrated a comprehensive overview on the most relevant solutions of prefabricated cladding systems and particularly the different typologies of precast concrete panels currently available on the market. Moreover, thanks to the application of the performance-bases building design (PBD) approach, it has been possible to associate the Chinese stakeholders' needs with the precast concrete panels performance requirements. This analysis has confirmed the current trend of big transformation and transition in which Chinese construction industry has been involved in the last few years. There is an important changing from quantity to quality orientation, boosted by the increasing economic wealth. Precast concrete panels, the most employed technology in high-rising buildings in China, should be more efficient in all aspects, showing better safety, durability, comfort, economic, environmental and aesthetic behaviour.

To follow these new directives and to help the professionals involved, the Thesis has proposed an innovative tool, "PANdwich: database for precast concrete panels technical solutions", able to make order in the huge field of prefabricated cladding systems technical solution and to offer an intuitive resource for the professionals. Thanks to user friendly interface and its availability online, it is a easy reference which can lead the professionals towards the best choice of technical solutions for cladding systems. The potentiality of this tool deals with its versatility and its ability to be implemented in order to be always updated following the latest solutions available on the market. Further research works could implement the aspects which has not been treated in this Thesis such as enlarge the database considering different final uses of the building (offices, retail, industrial), alternative typologies of cladding systems and, in the case of precast concrete panels, different typologies of them. The open issue regarding this tool is essentially the fact that it has never been tested by the professionals who can validated its real effectiveness.

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